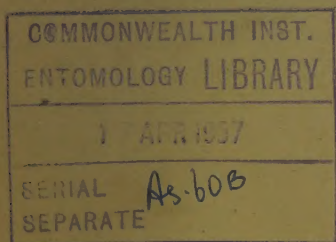


# THE INDIAN JOURNAL OF AGRICULTURAL SCIENCE



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## STUDIES ON FOLIAR DIAGNOSIS—I

### LEAF COMPOSITION OF THE DIFFERENTLY FERTILISED WHEAT CROP IN THE NEW EXPERIMENTAL PLOTS, PUSA AND ITS RELATION TO YIELD AND FERTILISER TREATMENT

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(Received for Publication on January 6, 1955)

(With 5 Text-figures)

THE complex soil plant inter-relationships are well-known and the inadequacy of soil analysis, alone for fixing proper manurial schedules for individual crops in the field, is recognised. A knowledge of the rate of availability of the different nutrients to the crop and of the course of nutrition of the crop during its different stages of growth is also necessary.

As a result, plant tissue tests were developed by Hoffer [1926], Morgan [1937] and Bray [1945] and the visual diagnosis of mineral deficiencies in the soil by Wallace [1944] and others. Importance of leaf analysis was first recognised by Lagatu and Maume [1930, 1935] and the technique was further extended by Thomas [1937] and Thomas and co-workers [1939, 1943, 1944 and 1946] who developed and applied foliar diagnosis technique for the study of balanced nutrition of potato, tobacco, maize and tomato crops and apple trees. Goodall and Gregory [1947] made a critical review of the work on foliar diagnosis.

In continuation of the earlier studies on methods of evaluating mineral deficiencies in the soil in this laboratory by Desai and Sundara Rao [1948], the present investigation was undertaken with the wheat crop (1946-47) of the New Permanent Manurial Experimental Plots, Pusa (Bihar), using the foliar diagnosis technique to follow the course of nutrition of the crop under different fertiliser treatments and fix the level and ratios of mineral nutrient contents in the loaf for maximum yields.

#### MATERIAL AND METHODS

Wheat (NP 52) was raised in the New Manurial Experimental Plots in the Punjab Field, Pusa (Bihar). The experimental area consisted of a hundred 1/40 acre plots arranged in ten randomised blocks of ten plots each.

The plan of the plots together with their treatments is shown in Appendix I.

A four-year, eight-course rotation—maize-oats-maize-peas-maize-wheat-maize—gram was followed.



The soil was calcareous sandy loam. The soil type was deep and friable, the difference between soil and subsoil being scarcely noticeable. The pH was 7.3. The soil was particularly poor in organic matter and responded to the two principal fertilizer elements, nitrogen and phosphoric acid.

#### *The method of sampling of leaves*

The fourth leaf from the base of the main flowering stem was taken with an inch of the sheath from the plant. The leaves were taken from all the plants in the quarter of the plot demarcated for each sampling. In all, three sets of leaf samples were collected.

The first sampling of leaves was made on January 13, 1947 when the crop in all the plots had completed tillering. The second sample was collected after an interval of 17 days, i.e. on January 30, when the plants were in short blade stage and the third sample was collected on February 12, at a stage when the inflorescence had fully emerged.

The composite sample from each treatment was dried soon after collection at 80°C. The dried samples were finally ground and passed through a sieve of 1 mm. diameter, thoroughly mixed and transferred to a glass container fitted with air-tight stoppers.

The leaf samples were analysed for nitrogen, phosphoric acid, potash, lime and magnesia. Calcium was precipitated as calcium oxalate and titrated against standard  $\text{KMnO}_4$ . Magnesium was precipitated as magnesium ammonium phosphate and after ignition weighed as magnesium pyro-phosphate while potassium was determined by the volumetric cobalti nitrite method. Phosphoric acid was determined by the volumetric method [A. O. A. C. 1935] based on Pemberton's original titration of yellow precipitate of phosphomolybdate with standard hydroxide. Nitrogen was determined by the modified Kjeldahl method [Cotton, 1945] so as to permit the reduction of nitrates. The results were calculated on oven dry basis.

### RESULTS

The mechanical and chemical analysis of the soil in Table I shows the nature and mineral status of the soil of these experimental plots. With a view to correlate the leaf analysis data with the productivity levels of the plots, the mean yields of grain and straw in the different treatments were recorded. These are given in Table II.



TABLE I

*Chemical and physical composition of the soil of Pusa Botanical sub-station*

Location : Punjab Field Experimental Area (West)—Plot I (no manure plot)

Serial No.	Head of analysis	Per cent
<i>A. Chemical Composition</i>		
1	Moisture	0.44
2	Loss on ignition	1.05
3	Insoluble mineral matter	62.68
4	Iron ( $\text{Fe}_2\text{O}_3$ )	2.20
5	Alumina.....( $\text{Al}_2\text{O}_3$ )	2.34
6	Lime.....( $\text{CaO}$ )	16.77
7	Magnesia.....( $\text{MgO}$ )	1.68
8	Potash.....( $\text{K}_2\text{O}$ )	0.385
9	Soda.....( $\text{Na}_2\text{O}$ )	0.037
10	Phosphoric acid ( $\text{P}_2\text{O}_5$ )	0.101
11	Carbon dioxide ( $\text{CO}_2$ )	12.71
12	Sulphuric acid ( $\text{SO}_3$ )	0.024
13	Nitrogen	0.033
14	Available potash ( $\text{K}_2\text{O}$ )	0.0041
15	Available phosphoric acid ( $\text{P}_2\text{O}_5$ )	0.0003
16	Humus	0.60
<i>B. Mechanical Analysis of Pusa Soil (Mem. Dept. Agric. India Chem. Sci. (1921). 5 : 200</i>		
1	Fine gravel	19.64
2	Sand	45.83
3	Fine sand	16.50
4	Silt	9.43
5	Fine silt	7.60
6	Clay	1.00

Analytical Records of *Imp. Agric. Chemist* (vide Appendix vi p. 104).

TABLE II

*Plots with fertiliser treatments and yields of wheat (grain and straw)*

Plot No.	Fertiliser treatments with N, P <sub>2</sub> O <sub>5</sub> and K <sub>2</sub> O equivalent applied to each plot	Symbol	Yield per plot 1/40 acre* (Mean of 5 plots)	
			Grain (lb.)	Straw (lb.)
2, 36, 44, 74 and 87	A. No manure	..	6.76	22.84
1, 37, 45, 80 and 84	B. Farmyard manure at 8000 lb. per acre. Total amount to be applied in the last week of April or first week of May	..	11.53	35.67
5, 40, 41, 75 and 89	C. Rape cake at 40 lb. of N per acre. Half to be applied just before <i>kharif</i> sowing and half to be applied at the time of last interculture	..	11.42	36.98
6, 39, 48, 79 and 81	D. Sulphate of ammonia at 40 lb. N per acre. Half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	N	12.83	35.18
7, 38, 43, 76 and 88	E. Sulphate of potash at 50 lb. K <sub>2</sub> O per acre, half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	K	6.14	19.86
10, 34, 46, 77 and 85	F. Superphosphate at 80 lb. P <sub>2</sub> O <sub>5</sub> per acre, half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	P	7.63	25.58
8, 32, 49, 71 and 82	G. Sulphate of potash at 50 lb. K <sub>2</sub> O per acre and superphosphate at 80 lb. P <sub>2</sub> O <sub>5</sub> per acre, half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	PK	6.65	20.95
3, 35, 47, 78 and 90	H. Sulphate of ammonia at 40 lb. N per acre plus superphosphate at 80 lb. P <sub>2</sub> O <sub>5</sub> per acre plus sulphate of potash at 50 lb. K <sub>2</sub> O per acre. Half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	NPK	11.81	35.79
4, 33, 42, 73 and 86	I. Sulphate of ammonia at 40 lb. N per acre plus superphosphate at 80 lb. P <sub>2</sub> O <sub>5</sub> per acre. Half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	NP	14.23	41.78
9, 31, 50, 72 and 83	I. Sulphate of ammonia at 40 lb. N per acre plus sulphate of potash at 50 lb. K <sub>2</sub> O per acre. Half before <i>kharif</i> sowing and half before <i>rabi</i> sowing	..	12.29	34.11

\*Only the residual effects were in evidence on this wheat crop as the manures were applied before sowing the previous *kharif* crop.

The percentage of nitrogen, phosphoric acid, potash, lime and magnesia in the fourth leaf from the base of the main flowering stem at the different sampling dates are shown in Fig. 1. The intensities of nutrition as shown by the sum of percentages of N,  $P_2O_5$  and  $K_2O$  were plotted as ordinates and the sampling dates as abscissae in Fig. 2. The equilibrium between N,  $P_2O_5$  and  $K_2O$  in the leaf at the time of sampling was expressed by NPK unit. This unit was derived by converting the percentage composition with respect to N,  $P_2O_5$  and  $K_2O$  into milligram equivalents and then finding the proportion each bears to the milligram equivalent of the total. The results were multiplied by 100 to avoid fractional quantities. The mean values of the intensities of nutrition and of the composition of NPK units are presented in Table.III.

## DISCUSSION

The nitrogen percentages in the leaves of plants (Fig. I) receiving treatments that did not include N showed no wide differences among themselves while these were definitely lower than those in N and NP treatments. Probably the rate of availability of nitrogen in the soil was lower than the crop requirements for high yields and extraneous addition of nitrogen was necessary. By comparing NPK and NP treatments it may be seen that the inclusion of potash had some adverse effect on the uptake of N by the leaves. This is similar to an observation made by Tyner and Webb [1946] working with corn. Usually nitrogen content of the leaf below 2.5 per cent at the first stage of sampling indicated a deficiency of nitrogen and was associated with low yield.

TABLE III

*The mean value of the intensities of nutrition and of the composition of the NPK-Units of the respective treatments during the growth cycle*

Treatment	Composition of NPK-Units (Mean of 3 samplings)			Intensity of nutri- tion (mean of 3 sam- plings)	Mean yield of grain and straw per plot 1/40 acre size	
	N	$P_2O_5$	$K_2O$		Grains (lb.)	Straw (lb.)
I (NP) $(NH_4)_2SO_4$ + Super	66.49	6.85	26.66	6.54	14.23	41.78
D. (N) as $(NH_4)_2SO_4$	68.07	5.43	26.50	6.74	12.83	35.18
J. (NK) $(NH_4)_2SO_4$ + $K_2SO_4$	63.32	6.54	30.14	6.20	12.29	34.11
H. (NPK)	60.52	8.05	31.40	6.29	11.81	35.79
B. (F.Y.M.)	58.23	9.43	32.65	6.60	11.53	35.67
C. (Rape Cake)	59.99	8.27	31.75	6.62	11.42	36.98
F. (P) as Super	61.92	8.66	29.43	6.30	7.63	25.58
A. NO Manure	60.95	7.63	31.39	6.14	6.76	22.84
G. (PK) as Super $K_2SO_4$	60.11	10.32	29.56	5.99	6.65	20.95
E. (K) as $K_2SO_4$	64.31	6.78	28.90	5.99	6.14	19.86

For grain yield per plot

S.E. = 0.904

C.D. = 2.53

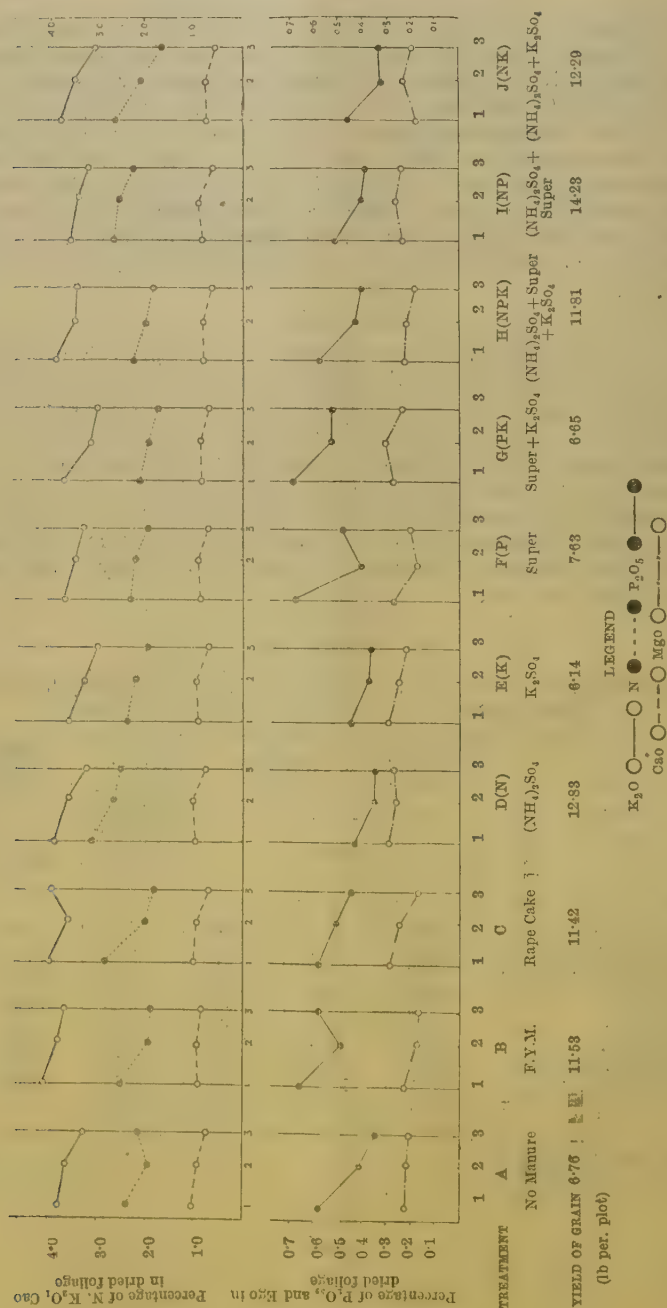
Fig. 1.—Changes during the growth cycle in the contents of N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, CaO and MgO in the fourth leaf resulting from the different treatments.



TABLE IV

*The mean values of the composition of the Ca-Mg-K Unit and yield*

Treatment	Mean			Yield of grain in lb. per $\frac{1}{10}$ acre
	CaO	MgO	K <sub>2</sub> O	
I. (NP) as (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> + Super	26.50	11.00	62.50	14.23
D (N) as (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub>	27.12	10.95	61.93	12.83
J (NK) as (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> + K <sub>2</sub> SO <sub>4</sub>	24.65	9.49	65.86	12.29
H. (NPK) as (NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> + Super + K <sub>2</sub> SO <sub>4</sub>	24.59	9.16	66.25	11.81
B. (F. Y. M.)	26.40	7.50	66.10	11.53
C (Rape Cake)	25.36	9.13	65.51	11.42
F (P) as Super	26.45	9.35	64.20	7.63
A. No Manure	27.00	9.10	63.90	6.76
G. P. K. as super + K <sub>2</sub> SO <sub>4</sub>	26.64	12.03	61.31	6.65
E (K) as K <sub>2</sub> SO <sub>4</sub>	27.66	10.92	61.42	6.14

The differences were much narrowed down at the third stage of sampling.

Treatments which included P<sub>2</sub>O<sub>5</sub> either in organic or inorganic form increased the P<sub>2</sub>O<sub>5</sub> content of the leaves (Fig. I) as compared to those that do not include P<sub>2</sub>O<sub>5</sub> treatment except the no-manure treatment. This might be due to the high concentration of P<sub>2</sub>O<sub>5</sub> distributed in a smaller portion of plant material. No correlation between P<sub>2</sub>O<sub>5</sub> content and crop yield could be observed.

The differences between K<sub>2</sub>O content in the leaves (Fig. I) under different treatments were slight except in NP treatment where a low K<sub>2</sub>O content was associated with high N and P<sub>2</sub>O<sub>5</sub> content.

In general, high N and P<sub>2</sub>O<sub>5</sub> contents in the leaves were observed in the treatments which included N and P and this was associated with high yields. A balanced level of N and P appears to be essential for better crop yields and the concentration of no single constituent can possibly be a safe guide unless the particular constituent is a serious limiting factor.

Curves indicating N content in the high yielding plots NP, N and NK (Fig. I, I, D and I) started at a relatively higher level than those of the low yielding plots indicating an adequate supply of nitrogen in the former. Throughout the growth cycle studied, the nitrogen content in the leaves of NP-treated crop was high and sustained as can be seen from the descent of the curve showing a steady supply of nitrogen from the soil.

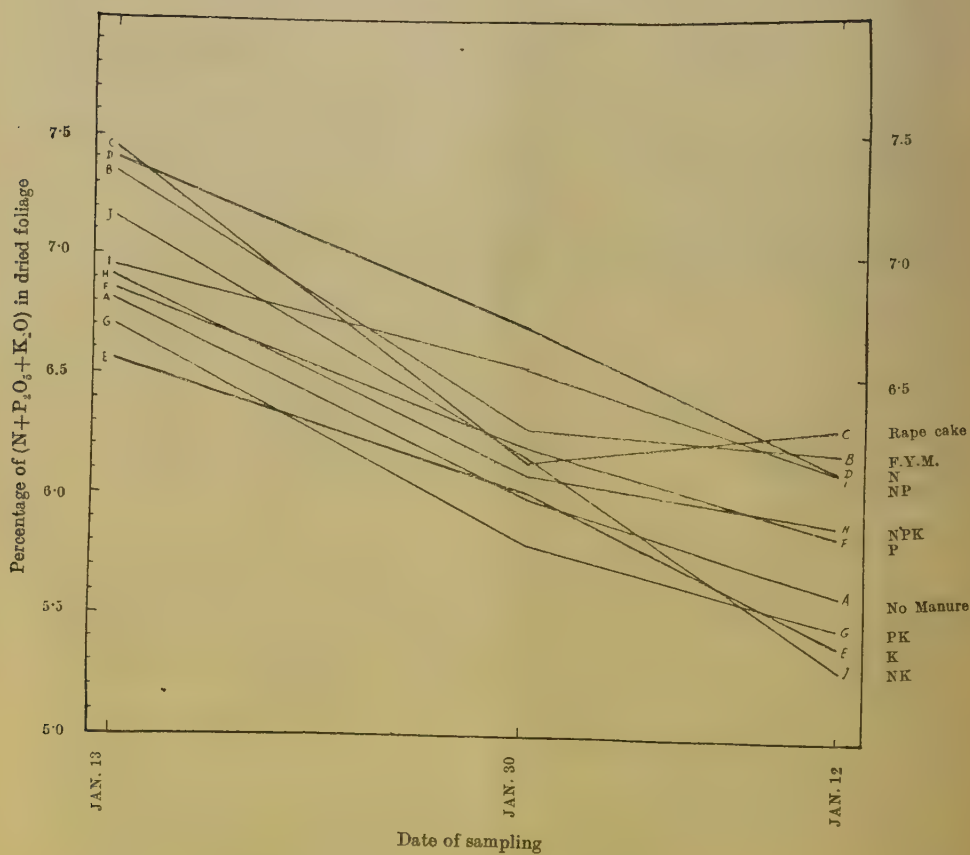


Fig. 2. The intensities of nutrition

The P curve did not conform to any single pattern while the calcium and Mg curves were more or less uniform. The association of high level of N and its gradual utilisation by the crop with high yields and the absence of any such relationship with other constituents was a clear indication that N was the dominant single factor limiting the crop yields.

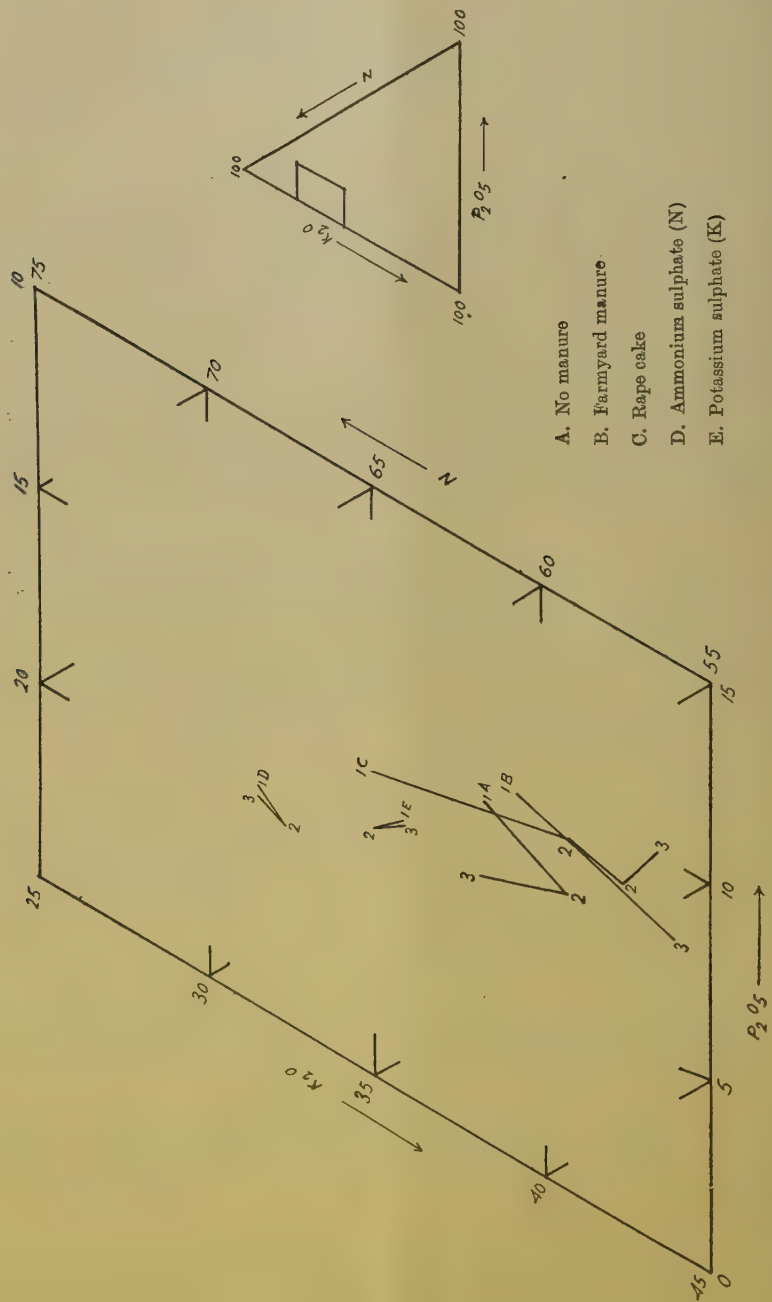
*Intensity of nutrition:* The course of variation in the intensities of nutrition ( $N + P_2O_5 + K_2O$ ) during different stages of sampling are shown in Fig. 2. The curve of plot NP started with an intensity value of 7 and had a more or less uniformly falling gradient indicating a steady and balanced nutrient supply. Intensities of nutrition lower than 7 to start with and a steep fall of these values with advancing age of leaves was the characteristic feature of the low yielding plots, unmanured, K, P and PK. The values were low on account of low levels of nitrogen. The NK curve started with high intensity but recorded a sharp fall due to the low N and  $P_2O_5$  value at the third sampling stage showing that unless N and  $P_2O_5$  were supplied to the soil, the crop could not obtain adequate amounts of both, throughout its quick growing period. This was in conformity with the mineral deficiency indications in Pusa soil obtained by chemical and microbiological methods [Desai and Sundara Rao, 1948] and Mitscherlich method and Indicator plant method [Sundara Rao, 1953].

*Changes in the  $N-P_2O_5-K_2O$  equilibrium with advancing age of leaves:* Curves showing variation in the  $N-P_2O_5-K_2O$  unit are shown in Fig. 3 and 4. The relationship between any three variables are usually represented by means of a trilinear diagram. The part of the triangle in which the values lie were shown enlarged to bring out clearly the variation of the equilibrium values in each treatment. The small triangle in the Fig. showed the entire triangle of which the diagram forms a portion. The numerals 1, 2, 3 were the co-ordinate points showing the N P K unit at the three successive sampling dates.

In the case of N P and N treatments the position of the curve high up toward apex N-100 per cent as compared to other treatments showed high proportion of N in N-P-K unit. The position of curve of no-treatment in the triangle away from  $P_2O_5=100$  as compared to F. Y. M. and rape cake (residual effects) indicated a low supply of  $P_2O_5$ . The curve of the NPK plot was similar to that of NP except that the former occupies in the triangle a position indicating low level of nitrogen utilisation from the soil.

While NP and K curves were similar so far as the N-P-K unit values were concerned, the yields were different, the former recording very high yields probably due to high mean intensity value (6.54) as compared to that of the latter (5.99) (Table III).

The absence of nitrogen in P and PK treatment resulted in an increase in the proportion of phosphoric acid and potash in the NPK unit at the expense of nitrogen throughout the growth period studied.

Fig. 3. Changes during the growth cycle in  $N-P_2O_5-K_2O$  equilibrium





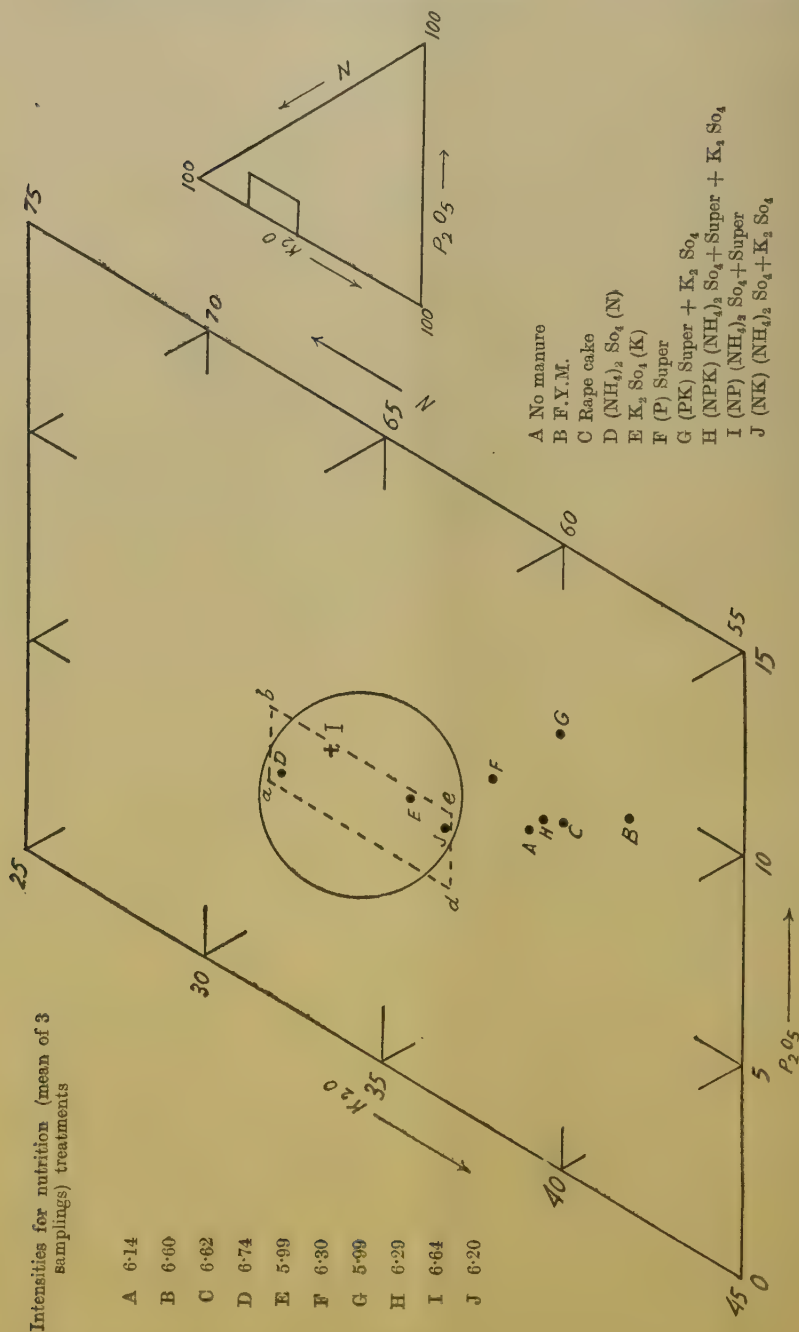


Fig. 5. Relative positions of the mean N-P-K units

The position of N P curve indicated an adequate equilibrium between elements P and K in association with high N content of leaves and this together with high intensity value appeared to be the characteristic feature of optimum nutrition of the crop, since this resulted in the maximum yield of the crop.

*Resultant foliar diagnosis indices.* The mean values for intensities and NPK units on the respective sampling dates represent an integration of all the changes in these values. This was represented by a single point on the triangle. The values of the mean NPK units, for the three samples together with mean intensities for various treatments are shown in Table III.

The magnitude of the variation in the intensity of nutrition and composition of the NPK unit between the maximum yielding treatment NP and the lowest yield was not quite large. However, closer examination of the relative differences in nutrition in the different treatments brought out the following interesting observations.

*Comparison of the mean intensities of nutrition and the mean NPK unit in relation to the optimum.* The nutrition of the plants on the lower yielding plots had the following relationships to the higher yielding plot (NP) which might be considered as the optimum :

In the case of the no-manure treatment, farmyard manure, and rape cake treatments (residual effects) K, P, PK, NPK and NK treatments, the proportion of nitrogen in the NPK unit was low, while in the N-treated plot the proportion of phosphoric acid was too low as compared to the optimum. The positions in the NPK units of the no-manure, F.Y.M. and rape cake treated plots were widely divergent.

The proportion of phosphoric acid in the NPK unit can, however, be increased by the application of phosphates whether alone or with potash.

The crop yields from plots where the residual effects of farmyard manure and cake were in evidence were not very much different from that of N or N K or NPK treated plots indicating that a high intensity of nutrition could compensate to some extent  $N-P_2O_5-K_2O$  equilibrium well below the optimum. However, good equilibrium, as in the case of potash application, could not compensate for low intensity of nutrition well below the optimum.

It appears from this investigation that with adequate intensity of nutrition, the nearer a point approached to that of optimum the higher would be the yield.

The NPK equilibrium points nearest to the optimum point (N.P. treatment) were grouped in a circle (Fig. 5) which constituted the loci within which points for all fertile plots should lie. The co-ordinate points of treatments N, NK and K lie within the circle. The first two treatments gave high yields because of their high intensity value compensated for the slight disequilibrium in the NPK units. The last treatment because of a relatively good  $N-P_2O_5-KO_2$  equilibrium could fall within the circle but as the intensity of nutrition, an important factor for productivity was inferior to that of the optimum, the yields were low.

In a later investigation at this Institute with barley crop, Chandrasekhara and Sundara Rao [1956] showed that with the upper and lower limits of mean N-P-K unit values of the high yielding plots, a parallelogram to include all the high yielding plots could be drawn leaving all the low yielding ones outside the parallelogram. One advantage of the parallelogram appears to be that the upper and lower limits of mean NPK unit for balanced nutrition can be shown in the figure. This enables the development of a suitable manurial schedule so that the NPK equilibrium point be shifted to fall within the parallelogram. Similar observations could also be recorded in the present wheat crop where the parallelogram concept mentioned above fitted well. In this experiment a mean composition of the NPK unit between the limits  $N=63$  to  $68$ ,  $P_2O_5=5.5$  to  $7$  and  $K_2O=31.5$  to  $25.0$  was found to be indicative of high yields and when these limits were plotted in the trilinear graph, they formed the four corners of a parallelogram "a b c d" shown in Fig. 5. The lines a d, b c represent the lines  $P_2O_5=5.5$  and  $7$ , while the lines d c, a b represent  $N=63$  and  $69$ . The angular points b and d are on the lines  $K_2O=31.5$  and  $25.0$ .

*Relation between CaO, MgO and K<sub>2</sub>O* : Table IV shows the quantities of CaO, MgO and K<sub>2</sub>O expressed as (i) percentage values, (ii) milligram equivalents and (iii) Ca-Mg-K units. The Ca-Mg-K unit is derived in the same manner as the N-P-K unit.

Thomas [1941] observed that the relation between Ca-Mg-K unit under optimum growth was a linear function and two of the variables were capable of expression by a linear equation. In the present investigation, however, the drifts with maturity in the CaO-MgO-K<sub>2</sub>O equilibrium resulting from the different treatments deviated from a linear function in all the treatments given, including the optimum.

#### SUMMARY

In the foliar diagnosis studies conducted with the wheat crop in 1946-47, of Permanent Manurial Experiments at Pusa (Bihar) it was observed that :

(1) In general, in the treatments which included N and P, high nitrogen and  $P_2O_5$  contents in the wheat were noticed and this was associated with high yields. A balanced level of N and P appears to be essential for better crop yields.

(2) At different stages of sampling the high yielding plots N P, N and NK showed high nitrogen content and started at a relatively higher level than those of the low yielding plots. This indicated that the nitrogen requirements of the crop could be met in the soil only when adequate amounts of nitrogenous fertilisers were added. Nitrogen was the dominating single factor limiting crop yields in this soil.

(3) Phosphoric acid appeared to be the second limiting factor, since the inclusion of phosphatic fertiliser in addition to nitrogen resulted in a direct increase in the  $P_2O_5$  content and a simultaneous increase in crop yields.



(4) The curve of plot NP started with an intensity value of 7 and had a more or less uniformly falling gradient indicating a steady and balanced nutrient supply. Intensity of nutrition lower than 7 at start and steep fall of these values with advancing age of leaves was characteristic of low yielding plots.

(5) High intensity values and an adequate equilibrium in the N, P and K contents in association with high nitrogen content in the leaves appear to be characteristic feature of optimum nutrition of the crop, since this resulted in maximum yield.

(6) The parallelogram concept developed by Chandrasekhara and Sundara Rao fitted well in these studies. With upper and lower limits of mean NPK unit values of high yielding plots, a parallelogram to include all the high yielding plots could be drawn leaving all the low yielding ones outside the parallelogram. A mean composition of the NPK unit between the limits  $N=63$  to  $68$ ,  $P_2O_5=5.5$  to  $7$  and  $K_2O=31.5$  to  $25$  was found to indicate high yields. These limits when plotted on the triangular diagram formed the four corners of the parallelogram.

#### ACKNOWLEDGMENTS

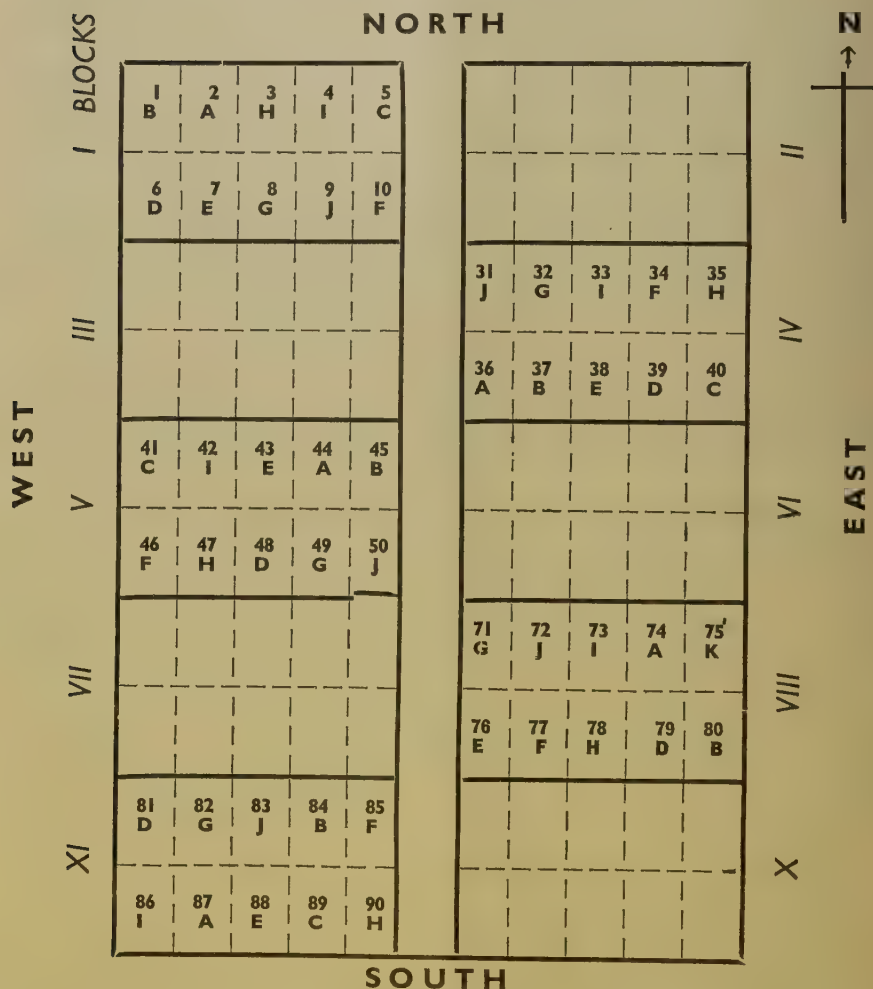
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## PLAN OF

Lay-out of New Manurial Experiment, Punjab Field.  
Botanical Sub-Station, Pusa



Total area: 2.5 acres Block Size 122' × 89.26' (10 Plots)

Plot Size—44.63' by 24.2'

Plots used for foliar diagnosis studies:—

Block.	Plot Nos.
I	1 to 10
IV	31 - 40
V	41 - 50
VIII	71 - 80
IX	81 - 90

## TREATMENTS

A	No Manure	F	(P) Super
B	F.Y.M.	G	(PK) Super + K <sub>2</sub> So <sub>4</sub>
C	Rape Cake	H	(NPK) (NH <sub>4</sub> ) <sub>2</sub> So <sub>4</sub> + Super + K <sub>2</sub> So <sub>4</sub>
D	(NH <sub>4</sub> ) <sub>2</sub> So <sub>4</sub> (N)	I	(NP) (NH <sub>4</sub> ) <sub>4</sub> Fo <sub>4</sub> + Super
E	K <sub>2</sub> So <sub>4</sub> (K)	J	(NK) (NH) So <sub>4</sub> + K <sub>2</sub> So <sub>4</sub>

## STUDIES ON FOLIAR DIAGNOSIS—II

### LEAF COMPOSITION OF THE DIFFERENTLY FERTILISED BARLEY CROP IN THE OLD PERMANENT MANURIAL EXPERIMENTAL PLOTS, PUSA (BIHAR) AND ITS RELATION TO YIELD AND FERTILISER TREATMENT

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(with 4 Text-figures )

IN Part I, Sundara, Rao and Krishnarao [1956] discussed the foliar diagnosis studies with wheat crop in the New Manurial Experimental Plots, Pusa (Bihar). This article deals with the foliar diagnosis studies on barley crop (1947-48) grown in the Old Permanent Manurial Experimental Plots at the same place. These plots were adjacent to the New Manurial Plots and as such the soil was of the same chemical and mechanical composition as that described in Part I.

The rotation followed in the manurial experiment was maize-peas ; maize-barley ; maize-arhar\* ; maize-wheat. The treatments were as shown below :

Plot No.	Treatments	Symbol
1.	No manure	Check I
2.	Farmyard manure at 4,000 lb. per acre	FYM (4,000)
3.	Farmyard manure at 8,000 lb. per acre	FYM (8,000)
4.	Farmyard manure at 4,000 lb. per acre Rape cake to supply 20 lb. of N per acre to be applied at the time of last interculture	FYM+Ec
5.	Rape cake at 40 lb. of N per acre, half to be applied just before <i>kharif</i> sowing and the rest at the time of last interculture	Re
6.	Sulphate of ammonia at 40 lb. per acre, half before <i>kharif</i> and half before <i>rabi</i> , but in years when <i>arhar</i> is sown, one dose to be applied in <i>kharif</i>	N
7.	Sulphate of potash at 50 lb. K <sub>2</sub> O per acre, application half in <i>kharif</i> and half in <i>rabi</i>	K

\* *Cajanus cajan*

Plot No.	Treatments	Symbol
8.	Superphosphate at 80 lb. $P_2O_5$ per acre, application as in Plot 7	P
9.	Sulphate of potash at 50 lb. $K_2O$ per acre + super 80 lb. $P_2O_5$ per acre, application as in Plot 7	K+P
10.	Sulphate of potash at 50 lb. $K_2O$ per acre + sulphate of ammonia at 40 lb. + superphosphate at 80 lb. $P_2O_5$ per acre	N+P+K
11.	Sulphate of ammonia 40 lb. N per acre + super at 80 lb. per acre, application as in Plot 7	N+P
12.	Green manure with a purely cereal rotation	Gm+Ce
13.	No-manure check Plot 2	Check II
14.	Sulphate of ammonia at 40 lb. per acre + sulphate of potash at 50 lb. $K_2O$ per acre, application as in Plot 7	N+K
15.	Green manure in rotation	
16.	As in Plot 15 plus super at 80 lb. $P_2O_5$ per acre to be applied with green manure only	Gm+P
17.	No legume crop and no green manure	No Gm and no Leg
18.	No manure-check Plot 3	Check III

The rotation for plots 1 to 11, 13, 14 and 15 were of the general type noted earlier. For Plot 12 where no legume was permitted and where a green manure was included, the rotation was (1) green manure-barley, (2) green manure-wheat, (3) green manure-barley and (4) green manure-wheat. For plots 15 and 16, where green manure was tested with a legume the rotation was (1) maize-peas, (2) green manure-barley, (3) maize-*arhar* and (4) green manure-wheat. For Plot 17, the rotation was (1) maize-barley, (2) maize-wheat, (3) maize-barley, and (4) maize-wheat. The varieties of crops used in the experiment were, barley : N.P. 21, Wheat : N.P. 52, *arhar* : N.P. 80. The crop in series A during the *rabi* season of 1947-48, was barley in all the plots except in Plots 12 and 17, where the crop was wheat. The crops were unirrigated. The arrangement of the plots was in strips of  $\frac{1}{4}$  of acre each.

These experimental plots were laid out in 1908. All the plots were receiving the same set of fertiliser treatments, and were under the same rotation since 1930, when the original plan was slightly altered, and as such the different fertility levels were well established. Each plot was of quarter of an acre area. For sampling, each plot was approximately divided into four strips longitudinally and the samples of the third leaf from the bottom was collected from one strip each time. The first sample was collected on December 11, 1947 when the crop was about 24 days old and thereafter at approximately fortnightly intervals. The leaf samples were immediately



dried at 100°C. The dried samples were finely ground and passed through a 1 mm. sieve, thoroughly mixed and transferred to glass containers with air-tight stoppers.

Nitrogen was determined by the modified Kjeldahl and Gunning method [A. O. A. C.—1930] as to permit the reduction of nitrate. For  $P_2O_5$  and  $K_2O$  the plant material was digested with the perchloric acid, nitric acid and sulphuric acid mixture [Piper, 1947].  $P_2O_5$  was determined by the colorimetric method using stannous chloride as a reducing agent and  $K_2O$  by precipitating potassium with platinum chloride and following the colorimetric method recommended by Snell and Snell [1941].

### RESULTS

The changes in the composition of the leaf with regard to N,  $P_2O_5$  and  $K_2O$  during the course of the growth at different stages of sampling are shown in Fig. 1. The sum of the percentages of N,  $P_2O_5$  and  $K_2O$  designated as the intensity of nutrition is plotted against the date of sampling in Figs. 2A and 2B. The changes in N— $P_2O_5$ — $K_2O$  unit calculated as in Part I [Sundara Rao and Kirshna Rao 1954] are shown in the trilinear diagram (Fig. 3) and the position of the mean N— $P_2O_5$ — $K_2O$  unit of the third leaf of the crop in each plot is plotted in the trilinear graph (Fig. 4). The yield of grain and straw, mean intensity and mean composition of the N— $P_2O_5$ — $K_2O$  unit in the third leaf are recorded in Table I.

TABLE I

*The yield of grain and straw, mean intensity and mean composition of the N— $P_2O_5$ — $K_2O$  unit in the third leaf of barley crop in the plots of the Permanent Manurial Experiment, Pusa (1947-48)*

Plot No.	Treatment	Yield of grain and straw in lb.	Mean intensity	Mean composition of		
				N	$P_2O_5$	$K_2O$
16	G. M. + P	613	12.1	62.6	9.0	28.4
4	F. Y. M. + R. C.	488	11.0	63.7	4.7	31.7
15	G. M.	484	12.7	64.2	6.3	29.5
3	F. Y. M. (8,000)	442	10.1	64.6	5.9	29.5
5	E. C.	412	11.8	64.1	4.1	31.8
8	P	410	10.9	64.8	7.1	28.1
11	N. P.	408	11.2	67.1	5.1	27.8
2	F. Y. M. (4,000)	384	10.6	60.4	10.0	29.6
10	N. P. K.	348	12.2	61.4	5.8	32.8
9	KP	318	10.8	60.5	9.2	30.3
6	N	248	12.0	63.3	3.0	28.7
7	K	238	11.5	66.6	4.6	28.8
14	NK	218	12.3	66.7	4.1	29.2
13	Check II	170	12.3	66.3	4.1	29.6
1	Check I	154	11.2	62.6	6.7	30.7
18	Check III	124	11.4	63.6	6.7	29.7

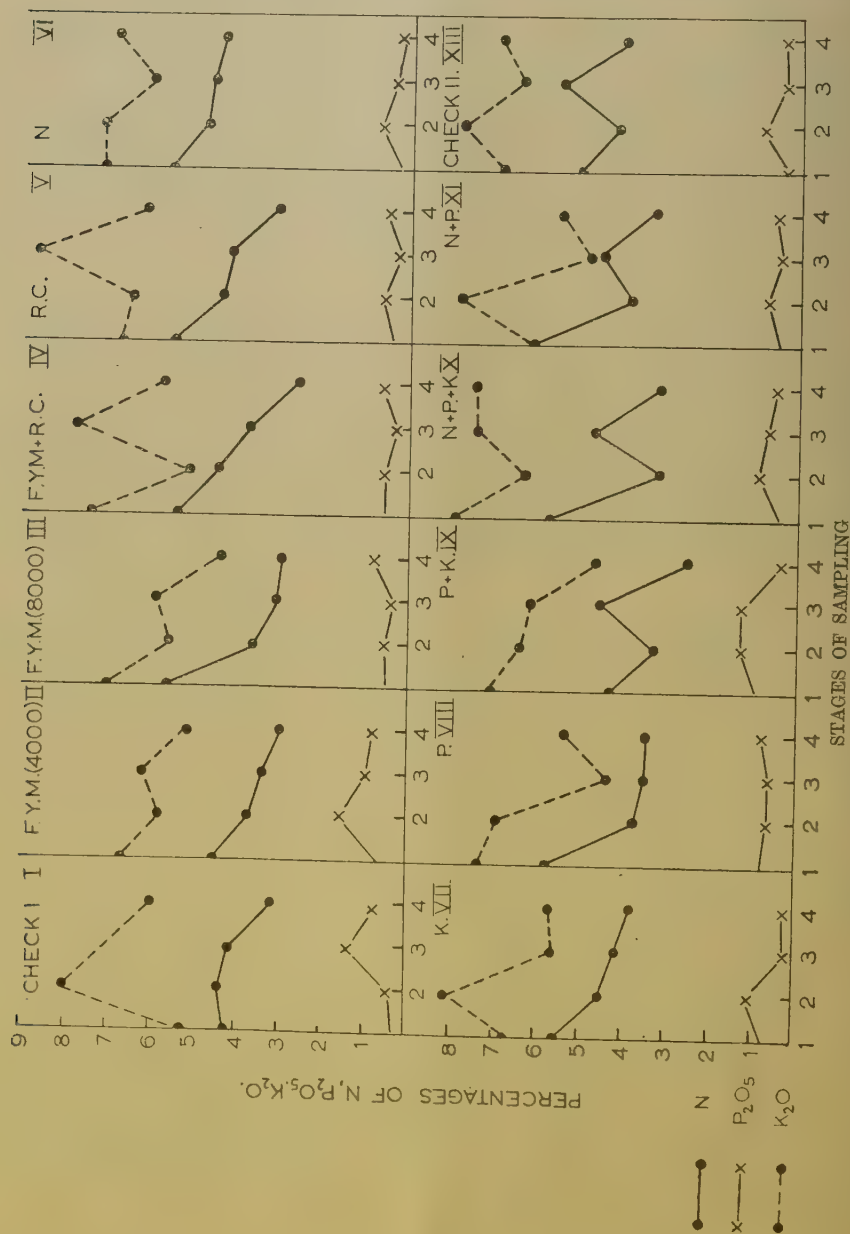


Fig. 1. Changes in the  $N$ ,  $P_2O_5$ ,  $K_2O$ , content of barley leaf

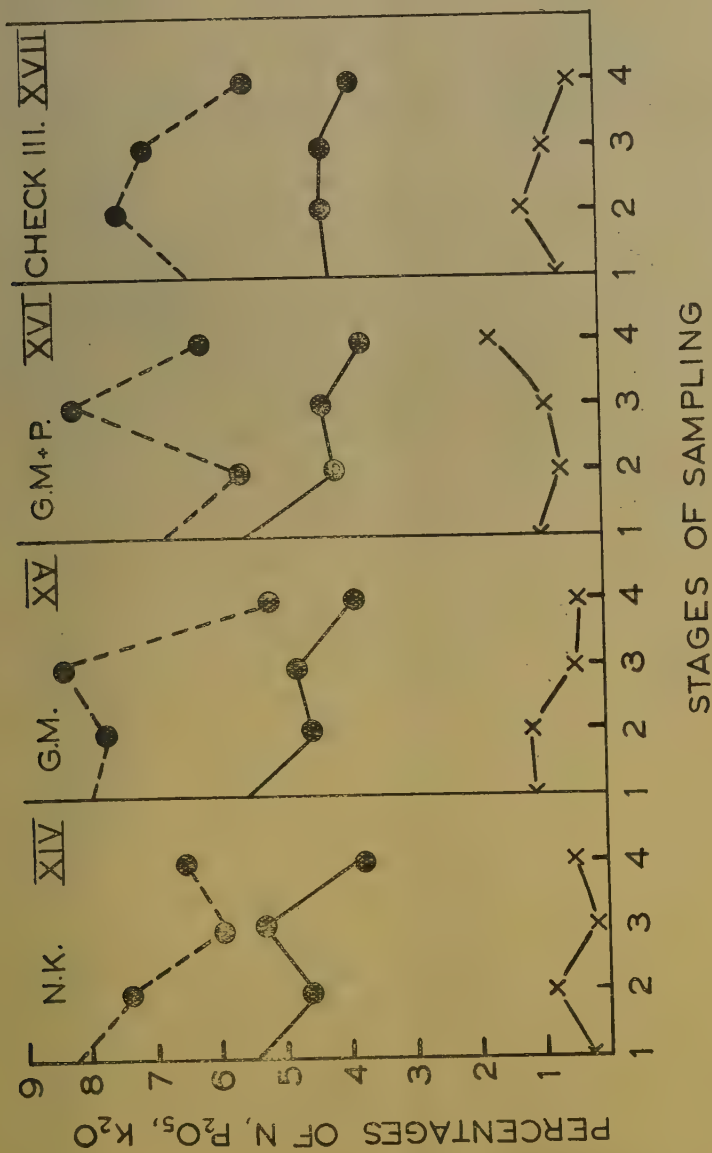


Fig. 1.—Cont. Changes in the N, P<sub>2</sub>O<sub>5</sub>, K<sub>2</sub>O, content of barley leaf

## DISCUSSION

*Changes in the composition of the leaf with regard to N,  $P_2O_5$  and  $K_2O$* 

A downward slope of the curve in Fig. 1 indicates mobilisation of the nutrient from the leaf into the plant tissue, while an upward trend indicates accumulation of the nutrient.

The nitrogen curves in Fig. 1 show in general a rapid fall in the initially high nitrogen of the leaf, from the first sample to the second and again from the third to the fourth. During the early part of plant growth, there was usually much meristematic activity giving rise to heavy demands on the nutrient reserves. Again during the period corresponding to the fourth sample, the plants were passing through a period of intense activity due to flowering. The mobilisation of leaf nitrogen to meet the demands was reflected in the downward trends described above. However, in the case of the unmanured Plots 17 and 13 a higher accumulation of nitrogen in the third sample as compared to the first was observed. Probably the poor nutritional condition of the plants stunted their growth and as such the nitrogen in the leaf could not be utilised by the growing parts of the plant.

The  $P_2O_5$  curves in Fig. 1 do not show much variation like the nitrogen graphs. The initial  $P_2O_5$  content was usually high in plots which received  $P_2O_5$  as compared to those which did not as can be seen from Table II.

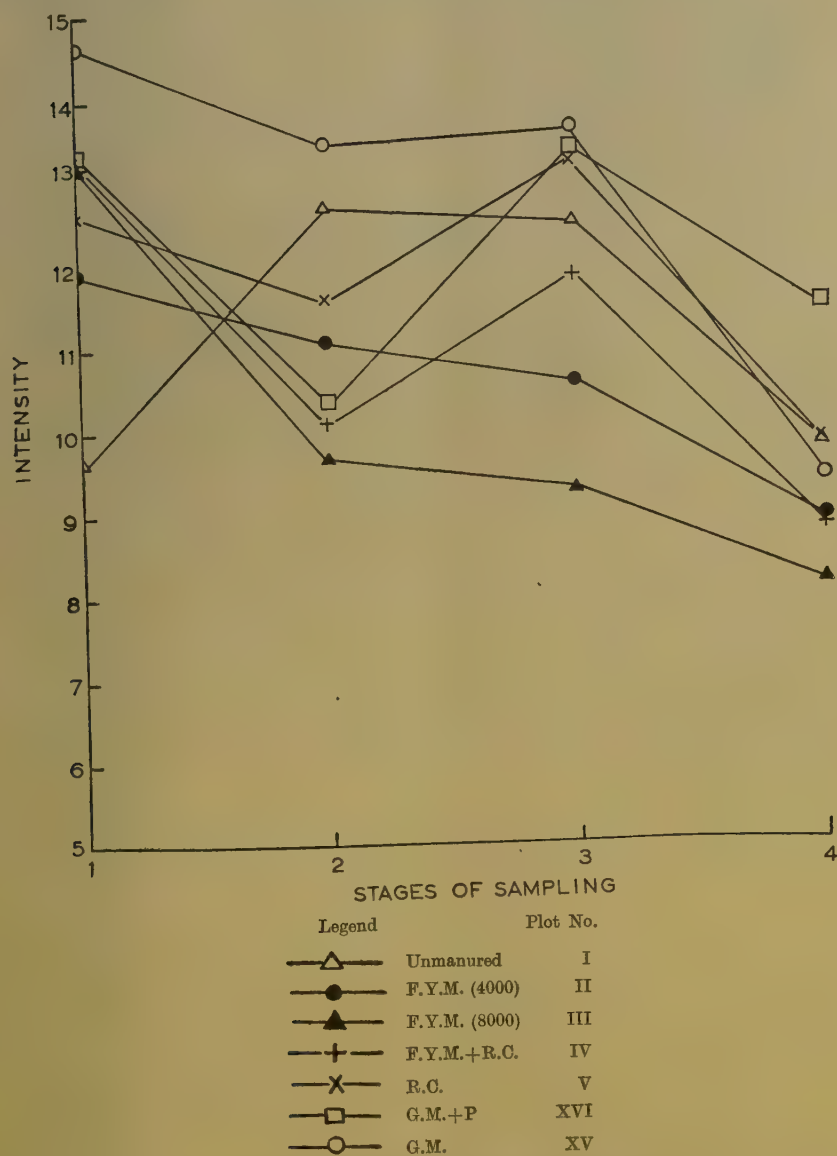
TABLE II

*Initial  $P_2O_5$  content in the barley leaf*

Plot No.	Treatment	Per cent $P_2O_5$
10	NPK	0.43
14	NK	0.39
9	PK	1.00
7	K	0.70
11	NP	0.49
6	N	0.21

However, the initial  $P_2O_5$  content in the leaf sample from Plot No. 15 receiving green manuring was greater than that in the case of the leaf samples from Plot No. 16 receiving green manures + superphosphate (Fig. 1). Further in Plot 15 there was mobilisation of leaf  $P_2O_5$  from the second sample onwards, while in Plot 16 receiving green manure and superphosphate an accumulation from the second stage was noticed. Goodall and Gregory [1947] attributed the high concentration in mature leaves to two causes, (i) luxury consumption when the



Fig. 2A. Changes in the intensity of nutrition (per cent N + per cent  $P_2O_5$  + per cent  $K_2O$ ) in the barley leaf

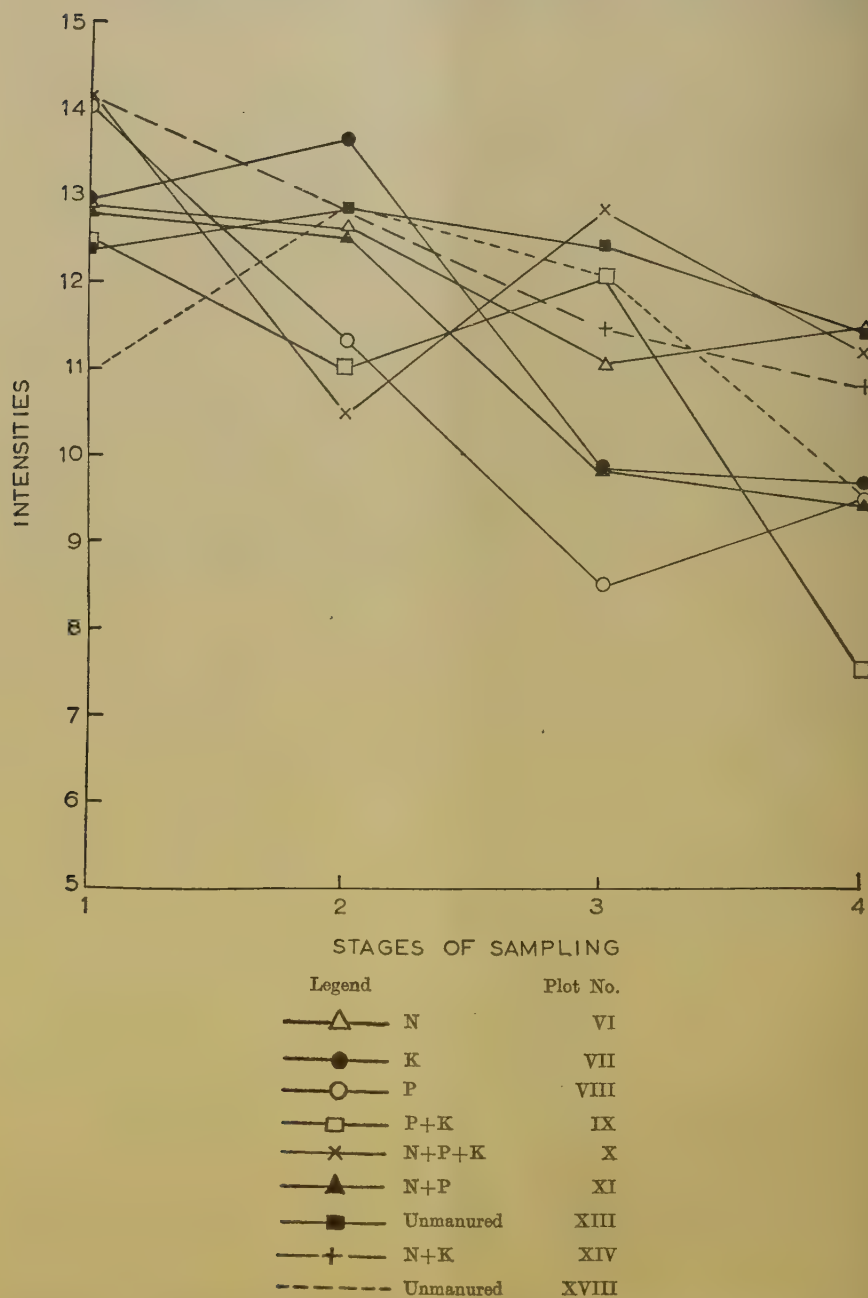


Fig. 2B. Changes in the intensity of nutrition (per cent N + per cent  $P_2O_5$  + per cent  $K_2O$ ) in the barley leaf

yield will be low and (ii) a high supplying power of the soil maintained throughout the growing period in which case the yield also was high. Plot No. 16 can be placed in the second category since the high yields as well as high content of  $P_2O_5$  of the leaves were due to the high availability of  $P_2O_5$  in the soil under this treatment. The decomposition of the green manure crop usually leads to the formation of organic acids and these acids together with carbonic acid render more phosphorus available to crop.

The  $K_2O$  curves were to a large extent similar to the nitrogen curves. The fertiliser effect on the  $K_2O$  content can be seen to some extent in Table III.

TABLE III

*Initial  $K_2O$  content in the leaf sample*

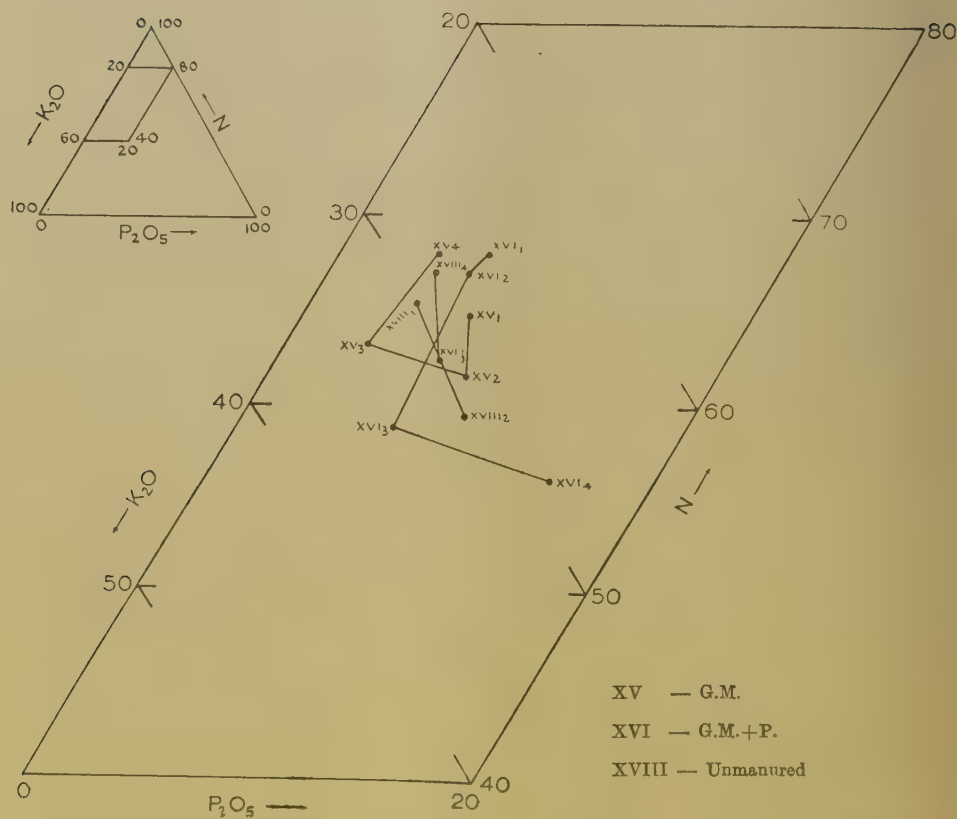
Plot No.	Treatment	Per cent $K_2O$ in the leaf at the first sample
10	NPK	8.0
11	NP	6.2
14	NK	8.2
6	N	7.2

*Progress of intensity of nutrition in the leaf from sample to sample*

As in the case of the percentage curves (Fig. 1) a downward trend of the curves in Figs. 2A and 2B indicates a mobilisation of the nutrients from the leaf to the plant tissues, while an upward trend shows an accumulation. Rapid mobilisation of the nutrients between the first and second sampling dates was associated with high yields, while an accumulation during this period invariably resulted in a low yield. The curves of the unmanured Plots 1, 13 and 18 and Plot 7 receiving sulphate of potash (Figs. 2A and 2B) showed an accumulation of nutrients at the stage mentioned above and all these plots gave low yields (Table I).

*Changes in the  $N-P_2O_5-K_2O$  unit*

The changes in the  $N-P_2O_5-K_2O$  unit in the unmanured Plot 18, green manure + super treated Plot 16 and the green manure treated Plot 15 are shown in Fig. 3 on the trilinear diagram. The part of the triangle in which the values lie is shown enlarged to bring out clearly the variation of the equilibrium values in each treatment. The small triangle in the figures show the entire triangle of which the diagram forms a portion. The numerals 1, 2 and 3 are the co-ordinate points showing the  $N-P_2O_5-K_2O$  unit at four successive sampling dates.

Fig. 3. Changes in N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O unit in barley leaf



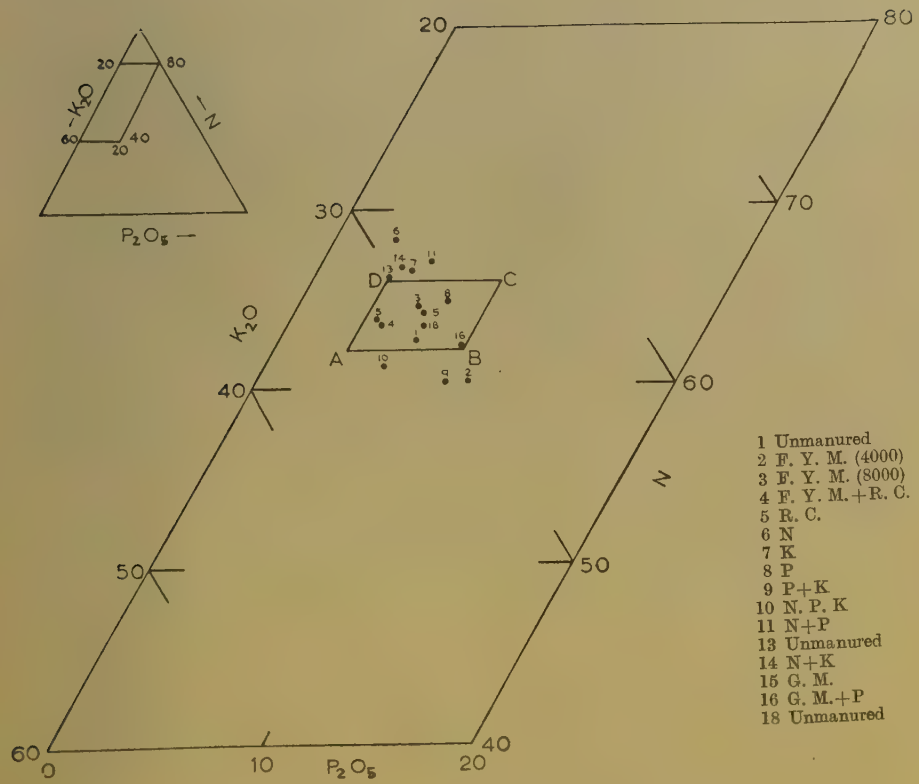


Fig. 4. Position of the mean N-P<sub>2</sub>O<sub>5</sub>-K<sub>2</sub>O unit of barley leaf.

In Plot 16 receiving green manure plus superphosphate there was a sudden fall in the value of N in the  $N-P_2O_5-K_2O$  unit from the second to the third sampling stages. In the fourth sample there was only a slight reduction in the N value but  $P_2O_5$  accumulated. In Plot 15 where green manure alone was applied,  $P_2O_5$  accumulation did not take place but an increase in the nitrogen value was observed. This difference in the performance of the two plots stresses the importance of phosphate addition in mobilising nitrogen. In the unmanured Plot 18, a rise in the N value in the  $N-P_2O_5-K_2O$  unit during the third and fourth sampling stages was observed which showed that the crop in the infertile plot could not mobilise nitrogen for growth purposes. A comparison of this plot with Plot 16 points to the need to supply nitrogen and phosphate in a suitable form so that a higher concentration of these in the soil solution may lead to better crop nutrition.

*Mean intensities and mean composition of the  $N-P_2O_5-K_2O$  unit*

Thomas and Mack [1939] showed that the increase in the mean intensity (mean of the intensities at the four dates of sampling) was associated with a corresponding increase in yield. No such regular relationship was observed in the present studies. However, in the case of the mean  $N-P_2O_5-K_2O$  unit a mean composition of the unit between the limits  $N=62$  to  $66$ ;  $P_2O_5=4$  to  $9$  and  $K_2O=34$  to  $25$  was found to be indicative of high yields. In Fig. 4, the points corresponding to the mean composition of the different treatments are shown in the trilinear diagram. Thomas and Mack [1939*b*] adopted the device of drawing a circle enclosing the plots which were near the optimum plot (highest yielding plot) and indicated that the composition of the mean  $N-P_2O_5-K_2O$  unit of the high yielding plots should normally fall in the circle within permissible limits. In the present studies, it was observed that when the limits specified earlier with regard to  $N-P_2O_5-K_2O$  unit were plotted on the trilinear graph, they formed the corners of the parallelogram shown as A B C D in Fig. 4. The lines A D and B C represent the lines  $P_2O_5=4$  and  $9$ , while the lines A B and D C represent  $N=62$  and  $66$ . The angular points A and C were on the lines  $K_2O=34$  and  $25$ .

*Crop nutrition in the differently fertilised plots, as indicated by foliar diagnosis technique*

Considering the yield data presented in Table I, plots can be grouped under three categories :

(i) the fertile plots comprising the Plot 16—green manure+super ; Plot 15 green—manure ; Plot 4—farmyard manure + rape cake ; Plot 3—farmyard manure at 8,000 lb. per acre ; Plot 5—rape cake ; Plot 8—superphosphate and Plot 11—sulphate of ammonia and superphosphate.

(ii) Moderately fertile plots :

Plot	Treatment
2	F. Y. M. at 4,000 lb. per acre
10	Sulphate of ammonia + super + sulphate of potash
9	Sulphate of potash + super

## (iii) Infertile plots :

Plot	Treatment
6	Sulphate of ammonia
7	Sulphate of potash
14	Sulphate of ammonia + sulphate of potash
13	} Unmanured plots
1	
8	

## (1) Fertile plots

## Plot 16

Treatment—green manure + superphosphate

This plot was characterised by a steady mobilisation of nitrogen throughout the growth period as can be seen from Fig. 1. The initial nitrogen content was 5.5, a high figure. From this figure it can be seen that the mobilisation of the nutrients was rapid both in the first and last stages. The mean composition of  $N-P_2O_5-K_2O$  unit was 62.6—9.0—28.4 and the point lies in Fig. 4 within the parallelogram. This plot thus possessed all the desirable characteristics of a fertile plot and gave the maximum yield.

## Plot 4

Treatment—farmyard manure + rape cake.

The mean  $N-P_2O_5-K_2O$  unit was 63.7—4.7—31.7 and the point lies within the parallelogram in Fig. 4. There was steady mobilisation of nitrogen as can be seen from the intensity curve in Fig. 2A.

## Plot 15

Treatment—green manure

The mean  $N-P_2O_5-K_2O$  unit value was 64.2—6.3—29.5 and the point lies within the parallelogram in Fig. 4. The initial nitrogen content in the leaf was 5.6, a high figure.

## Plot 3

Treatment—farmyard manure at 8,000 lb. per acre

The mean composition of the unit was 64.6—5.9—29.5 and the point lies within the parallelogram in Fig. 4. The percentage curves of  $N$ ,  $P_2O_5$  and  $K_2O$  in Fig. 1 were characteristic of steady and sustained nutrition. The intensity graph showed rapid mobilisation in the first and second stages.

*Plot 5*

## Treatment—Rape cake

The initial nitrogen content was 5.5, a high figure. The mean  $N-P_2O_5, K_2O$  unit value was 64.1—4.1—31.8 and the point falls within the parallelogram in Fig. 4. The curves in Figs. 1 and 2 show in general a steady mobilisation of nutrients during the growth of the crop.

*Plot 8*

## Treatment—Superphosphate

The initial nitrogen content in the leaf was 5.9, a high figure. The course of curve in Figs. 1 and 2 shows a steady and sustained mobilisation of nutrients. The mean  $N, P_2O_5, K_2O$  unit was 64.8—7.1—28.1. The point lies within the parallelogram in Fig. 4.

*Plot 11*

## Treatment—Sulphate of ammonia + superphosphate

The initial nitrogen content was high and the mobilisation of nutrients was satisfactory as can be seen from Figs. 1 and 2. The mean composition of the  $N, P_2O_5, K_2O$  unit was 67.1—5.1—27.8. The point falls just outside the parallelogram in Fig. 4. The yields were also the lowest among the high yielding plots.

*Moderately fertile plots :**Plot 2*

## Treatment—Farmyard manure at 4,000 lb. per acre

The initial nitrogen content was 4.53, a low value. The mean composition of the  $N-P_2O_5-K_2O$  unit was 60.4—10.0—29.6. The point lies outside the parallelogram in Fig. 4. The low yields as compared to the first category of plots may be due to low nitrogen content to start with and the consequent drift of the equilibrium point outside the parallelogram. This suggested a need to raise the nitrogen level. Actually F.Y.M. at 8,000 lb. gave much higher yield.

*Plot 10*

## Treatment—Sulphate of ammonia + superphosphate + sulphate of potash

The mean composition of the  $N-P_2O_5-K_2O$  unit was 60.5—9.2—30.3. The point in Fig. 4 lies outside the parallelogram. From Figs. 1 and 2B it can be seen that there was accumulation during the second and third stages of sampling which appear to be responsible for the low yields when compared with the plots of category 1.



*Plot 9*

Treatment—Sulphate of potash + superphosphate

The mean composition of the  $N-P_2O_5-K_2O$  unit was 60.5—9.2—40.3. The point falls outside the parallelogram. The initial nitrogen content was low and there was accumulation of nitrogen during the second and third sampling stages as can be seen from Fig. 1. Similar was the case in the intensity curve in Fig. 2B. These indicate that the crop in this plot lacked adequate initial nitrogen and its proper mobilisation.

*Infertile plots :**Plot 6*

Treatment—Sulphate of ammonia

The mean composition of the  $N-P_2O_5-K_2O$  unit was 68.3—3.6—28.7. The point lies outside the parallelogram in Fig. 4. There was accumulation of nutrients between the third and fourth sampling dates as can be seen from the intensity curves. From the value of  $N-P_2O_5-K_2O$  unit, the unbalance appears to be due to high concentration of N and low  $P_2O_5$  indicating that the application of  $P_2O_5$  in addition to nitrogen was necessary to correct the  $P_2O_5$  proportion in the leaf.

*Plot 7*

Treatment—Sulphate of potash

The mean composition of the  $N-P_2O_5-K_2O$  unit was 66.6—4.6—28.8. The point falls outside the parallelogram in Fig. 4. The intensity curve showed that there was accumulation of nutrients between the first and second sampling period and lack of mobilisation of nutrients between the third and fourth sampling dates.

*Plot 14*

Treatment—Sulphate of ammonia + sulphate of potash

The mean  $N-P_2O_5-K_2O$  unit was 66.7—4.1—29.2. The point lies outside the parallelogram in Fig. 4. Comparing the  $N-P_2O_5-K_2O$  unit in Plot 10 it may be seen that N and  $P_2O_5$  were unbalanced in this plot.

*Unmanured Plots, 13, 1 and 18*

It can be seen from the intensity curves in Figs. 2A and 2B that in the case of all the control plots there was accumulation of nutrients between the first and second stages whereas in fertile plots, there was mobilisation of nutrients which appeared to be the reason for the low yields.\*

The parallelogram concept developed in this paper was applied to the data in the "Studies with wheat crop" by Sundara Rao and Krishnarao [1954] and they observed that the upper and lower limit values for mean  $N-P_2O_5-K_2O$  unit could be represented by the corners of the parallelogram in the trilinear diagram.

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\* The fact that the two unmanured plots had mean  $N-P_2O_5-K_2O$  units within the limit values of the fertile plots and the reason for their low yields had to be sought in the intensity values which showed accumulation of nutrients between the first and second sampling dates, stresses that data of foliar diagnosis are to be interpreted with sufficient caution.

## SUMMARY

In the foliar diagnosis studies with barley crop in the Permanent Manurial Experiments at Pusa (Bihar) it was observed that :

(1) An accumulation of the nutrients N,  $P_2O_5$  and  $K_2O$  in the leaf at the early stages of growth indicated defective nutrition of the plant and resulted in diminished yield. A gradual and sustained mobilisation of the nutrients from the leaf tissue during this period was associated in general with high yields.

(2) The first sample of leaves from the plots receiving fertilisers which included  $P_2O_5$  or  $K_2O$  had high amounts of these respective constituents as compared to those receiving treatments which did not include these.

(3) A mean composition of N— $P_2O_5$ — $K_2O$  unit between the limits N=62—66,  $P_2O_5$ =4—9 and  $K_2O$ =34—25 was associated with high yields and could be considered representing balanced nutritional condition of the barley crop studied. These limits when plotted on the trilinear graph formed the corners of a parallelogram within which the points representing N— $P_2O_5$ — $K_2O$  units of the fertile plots fell.

## ACKNOWLEDGMENT

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## STUDIES IN THE DISEASES OF *MANGIFERA* *INDICA* LINN. IX\*

### ISOLATION OF A BRICK-KILN FUME CONSTITUENT CAUSING MANGO NECROSIS

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(With one Text-figure)

IN an earlier paper of the series [Das-Gupta and Verma, 1939], it has been pointed out that there exists a close relation between the presence of operating brick-kilns in the vicinity of orchards and the incidence of mango necrosis. Attempts were made by several workers to reproduce the disease experimentally by direct fumigation of mangoes with coal fumes [Sen, 1943; Das-Gupta and Verma, 1944] or by fumigating mangoes with such constituent gases of brick-kiln fumes which are known to be deleterious to plants [Pal, Chatterji and Ranjan, 1937; Ranjan and Jha, 1940; Das-Gupta, Verma and Sinha, 1941], but without any conclusive results. A critical estimate of the results obtained by these authors will appear in a later communication. Nevertheless, it seemed that brick-kiln fumes are causally related with mango necrosis, and another line of investigation was, therefore, started at Lucknow in 1948 when the constituents of brick-kiln fumes were absorbed in different organic solvents and these were then concentrated, fractionated and each constituent tested for necrotic activity on mango fruits. Results of this study were reported earlier in a preliminary note by Das-Gupta *et. al.* [1950]. This article gives a detailed account of this investigation.

#### METHODS

The method adopted consisted of passing the fumes into organic solvents directly from an operating kiln. The kiln selected for the purpose was the one situated near Nawab Ali orchard, Lucknow, which is heavily affected with mango necrosis every year.

The fume was drawn from the base of the chimney of the kiln by inserting a glass tube in the opening formed by removing the top-most brick of the checkwork, the tube extending to about two feet below the surface. The glass tube was connected with a rubber tubing to the fume inlet end of a train of bubblers, usually three, connected in a series and each having a capacity of 200 c.c. The outlet end of the train of bubblers was connected to an aspirator. The bubblers were cooled in ice throughout the aspiration to prevent undue evaporation of the solvent.

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The fumes were passed through the solvent for five hours. The fumed solvent so obtained was dehydrated over anhydrous sodium sulphate and filtered. The solvent was then distilled off and the residue left behind in the flask was weighed to determine the yield. The solvent soluble portion of the fumes is henceforth referred to as the 'residue'. The volume of fumed solvent finally distilled was used to calculate the yield.

The following seven solvents were utilised to absorb the constituents of the brick-kiln fumes: (i) ether, (ii) chloroform, (iii) petroleum ether (b.p. 60°-80°C.), (iv) benzene, (v) acetone, (vi) carbon tetrachloride, and (vii) ethyl alcohol.

Direct injection method of Das-Gupta and Verma [1940] was employed in the injection experiments. At the tip of the mango fruit two passages, one along the longitudinal axis of the fruit in the centre of the tip end and the other along the horizontal axis, intersecting each other at right angles were made by means of a sterile needle (diameter 0.8 mm.). Sterile injection fluid from an ampul was drawn in a sterilized syringe and injected into the tissue from one of the ends of the horizontal passage till the fluid flowed out from the two free ends of the passages. The gum appearing from the injured tissue due to puncturing effectively sealed all the apertures from communication with the outside atmosphere, making artificial sealing unnecessary.

#### EXPERIMENTAL

Experiments to prepare the residue were made using all the seven solvents, through which fumes were passed for five hours. The results are given in Table I.

TABLE I

*Yield of the residue from fumed solvents after fumigation for five hours*

Solvent	Average yield (per 500 c.c. of the solvent)
(i) Petroleum ether (b.p. 60°-80°C.)	4.0 mg.
(ii) Ether	3.0 mg.
(iii) Acetone	2.5 mg.
(iv) Ethyl alcohol	2.0 mg.
(v) Benzene	1.5 mg.
(vi) Chloroform	1.5 mg.
(vii) Carbon tetrachloride	1.0 mg.

Table I shows that all the seven solvents gave rather low yields. Among these the highest yield was given by petroleum ether (4.0 mg.), ether being the next (3.0 mg.).



Several experiments were carried out with ether using the same brick-kiln on different days but keeping constant the volume, rate and time for which the fumes were passed through ether. It was found that the yield varied considerably on different days, showing thereby that it was influenced by the working conditions of the brick-kiln. This was perhaps due to the fact that the brick-kiln being of the indigenous type, the temperature inside it kept on varying due to the irregular intervals of coke charging and the variation in the grade of coal used. As the yields from the solvent soluble portions of brick-kiln fumes are relatively very small, maximum number of absorbing units were set up at the kiln in order to facilitate the work.

### *Solubility and appearance of the residues*

The appearance and solubilities of the residues constituting the organic-solvent soluble portion of brick-kiln fumes are given in Table II.

TABLE II

### *Solubility and appearance of the residues*

Residue	Appearance under microscope	Solubility
Ether soluble portion of brick-kiln fumes	Consists of 3 fractions : (i) Pale yellow transparent crystals (ii) White semi-solid portion (iii) Brownish-yellow viscous liquid portion	Soluble in ether, chloroform, benzene, carbon tetrachloride, hot petroleum ether; partly soluble in cold petroleum ether, acetone, ethyl alcohol; insoluble in water
Petroleum ether (b.p. 60°-80°C.) soluble portion of brick-kiln fumes	Consists of 2 fractions : (i) Pale yellow transparent crystals (ii) Brownish-yellow viscous liquid portion	Same as ether soluble residue
Benzene soluble portion of brick-kiln fumes	Consists of 3 fractions : (i) Pale yellow transparent crystals (ii) White semi-solid portion (iii) Brownish-yellow viscous liquid portion	Same as ether soluble residue
Chloroform soluble portion of brick-kiln fumes	Consists of 2 fractions : (i) Pale yellow transparent crystals (ii) Brownish-yellow viscous liquid portion	Soluble in ether, chloroform, hot petroleum ether; partly soluble in cold petroleum ether and acetone; insoluble in water

TABLE II—*contd.**Solubility and appearance of the residues*

Residues	Appearance under microscope	Solubility
Carbon tetrachloride soluble portion of brick-kiln fumes	Consists of 2 fractions : (i) Pale yellow transparent crystals (ii) Brownish-yellow viscous liquid portion	Same as chloroform soluble residue
Acetone soluble portion of brick-kiln fumes	Consists of 2 fractions : (i) Yellowish-white solid portion (ii) Brown liquid portion	Soluble in acetone and ethyl alcohol; partly soluble in ether, chloroform, petroleum ether; liquid portion soluble in water
Ethyl alcohol soluble portion of brick-kiln fumes	Consists of 2 fractions : (i) Pale yellow transparent crystals (ii) Brownish-yellow liquid fractions	Same as acetone soluble residue

It will be seen from Table II that a fraction consisting of pale yellow, transparent crystals could be separated from all the residues except acetone. These crystals were fractionated from ether and petroleum ether soluble residues and tested for their necrotic activity on healthy mangoes.

*Isolation of the crystalline constituent of the ether soluble portion of brick-kiln fumes*

*The crystalline constituent :* The residue obtained from the ether soluble portion of brick-kiln fumes consisted of well-defined pale yellow crystals, a white semi-solid portion and a brownish yellow viscous liquid portion (Table II). The last two portions of the residues readily dissolved in cold petroleum ether, while the crystals did so to a very little extent. However, the three fractions, particularly the crystalline fraction, were not readily obtained. If the crude residue was taken up in ether and then allowed to crystallize with the slow evaporation of the solvent, the crystals appeared in seven days or more. But, if the crude residue was taken up in hot petroleum ether and then allowed to crystallise with the evaporation of the solvent, the crystals appeared within two to three days. The crystals were filtered from the mother liquor and washed three to four times with small quantities of petroleum ether and finally once with acetone. All the washings were collected with the original filtrate, which was again allowed to evaporate, when a second crop of crystals was obtained. This crop of crystals like the previous crop was separated from the rest of the constituents. It was possible to obtain two to three crops of crystals from a single sample of the residue and a brown viscous liquid was finally left over. The crystals obtained from all the crops had the same melting point.

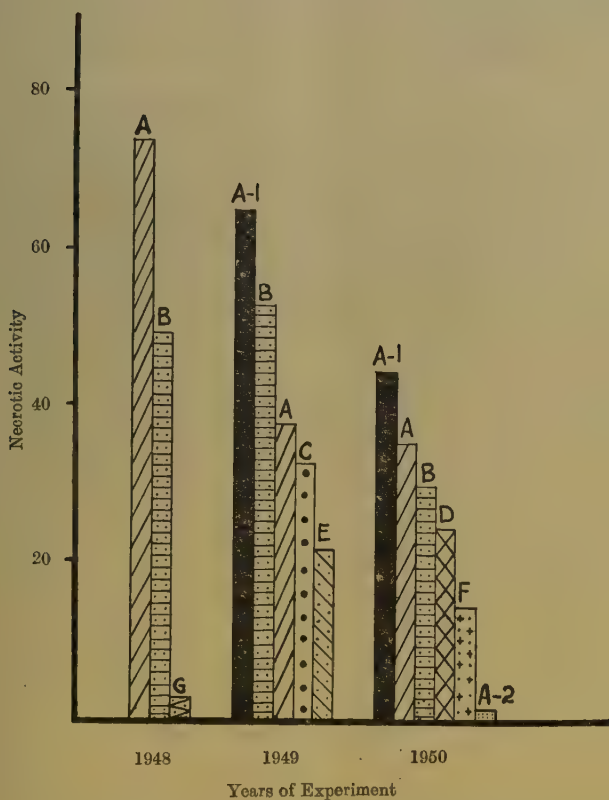


FIG. 1. Showing the necrotic activity of various residues comprising the portion of brick-kiln fumes soluble in ether (A), chloroform (B), benzene (C), petroleum ether (D), ethyl alcohol (E), acetone (F), carbon tetrachloride, and (G) the crystalline (A-1) and liquid (A-2) fractions of the ether soluble residue. Necrotic activity is expressed in terms of the percentage of mango fruits developing necrosis by injection with the residue or its fractions during the years 1948, 1949 and 1950.

This crystalline compound had a melting point of  $110.5^{\circ} \pm 0.5^{\circ}\text{C}$ . and gave positive tests for the presence of sulphur and chlorine.

*The viscous liquid fraction* : This was not subjected to further fractionation as results of the injection showed that it had very little necrotic activity as compared to the residue itself and the crystalline fraction.

*Isolation of the crystalline constituent of the petroleum ether soluble portion of brick-kiln fumes*

The petroleum ether soluble portion of fumes consisted of a crystalline fraction similar in appearance to that of the ether soluble portion and a brown viscous liquid fraction (Table II). The crystalline fraction of the petroleum ether soluble portion of the fumes could be separated successfully by the method described earlier for the ether soluble portion.

The crystalline compound had a melting point of  $110.5^{\circ} \pm 0.5^{\circ}\text{C}$ . and showed presence of sulphur and chlorine. Its mixed melting point with the crystalline compound obtained from the ether soluble portion of brick-kiln fumes was also  $110.5^{\circ} \pm 0.5^{\circ}\text{C}$ . which showed that the same compound was obtained from both these solvents.

*Necrotic activity of the solvent-soluble portion of brick-kiln fumes*

The necrotic activity of the solvent-soluble portion of brick-kiln fumes obtained in the form of residues from the various fumed organic solvents was tested by injecting them in healthy mangoes in healthy orchards by the direct injection method of Das-Gupta and Verma [1940]. Preliminary trials in the 1948 season indicated that symptoms of necrosis similar to that in necrotic mangoes in naturally diseased orchards appeared in injected mangoes. In the years 1949 and 1950, the necrotic activity of the crystalline and liquid fraction of the residue obtained from fumed ether was tested in a similar manner, and injection experiments with the various unfractionated residues from fumed solvents were repeated. From the results of these experiments, summarised in Fig. 1, it will be seen that the highest necrotic activity is shown by the crystalline fraction of the residue from fumed ether, while the liquid fraction of the same residue has negligible activity, showing thereby that the crystalline fraction is the specific necrosis-causing constituent of the brick-kiln fumes; whatever little activity is shown by the liquid fraction may be due to passing over of some crystalline fraction at the time of fractionation. The necrotic activity of unfractionated residues was much lower than that of the pure crystalline fraction. The relative efficacy of the residues from different fumed solvents varied.

## DISCUSSION

The attempt to isolate from brick-kiln fumes the constituent which may be responsible for the incidence of necrosis of mango fruit has proved successful. This substance which is soluble in several organic solvents, though to a varying degree, has been isolated by fractionation of the ether soluble portion of the fumes. The necrotic activity of the substance has been demonstrated by the production of typical symptoms of necrosis in healthy mangoes when injected in the tip region.

For example, the healthy mangoes injected with the solution of the crystalline fraction of the ether soluble portion of the fumes developed necrosis to a considerable extent. That the substance is present in chloroform, ether, benzene, ethyl alcohol and other solvents soluble portion of fumes, is also similarly demonstrated since in each case a definite percentage of mangoes showed necrosis. The efficacy of the different solvents varied as indicated in Fig. I. These results, however, should be taken as indicative of the trend of necrotic activity since injection experiments, carried out in different years, were not strictly comparable.

The incidence of mango necrosis in the orchards under normal conditions when brick-kilns are operating in the neighbourhood can thus be ascribed to the constant exposure of developing fruits to the active substance present in the fumes. The gradual decline of the disease in orchards in the absence of the causative agent in the atmosphere when the brick-kilns are shifted beyond a certain distance or when the brick-kilns stop operating is probably to be explained in the light of the present observations, as being due to the retention of the causative agent in the leaves which were affected by the fumes previously.

Work is in progress to isolate the disease-producing crystals in sufficient quantity for the purpose of chemical analysis and for experiments to test their necrotic activity by branch-injections and other methods avoiding the wounding of the mango fruits involved in the direct-injection method employed here.

As this active constituent of the brick-kiln fumes has been isolated only in a very small quantity, it has not been possible to carry out its analysis. The preliminary tests, however, show that the substance is a sulphur and chlorine containing compound, melting at  $110.5^{\circ}\pm 0.5^{\circ}\text{C}$ .

#### SUMMARY

Isolation of a constituent of the brick-kiln fumes responsible for causing mango necrosis is described. The brick-kiln fumes were passed through seven organic solvents, viz. acetone, benzene, carbon tetrachloride, chloroform, ethyl alcohol, ether and petroleum ether. The fumed solvents on distillation gave a residue in each case. Fractionation of the residue obtained from fumed ether and petroleum ether yielded a crystalline compound containing sulphur and chlorine and having a melting point of  $110.5^{\circ}\text{C}.\pm 0.5^{\circ}\text{C}$ .

Healthy mango fruits developed typical symptoms of necrosis when injected with a solution of the crystalline fraction. Unfractionated residues from fumed solvents also caused a similar effect, but the percentage of disease production by these was lower than that when crystalline fraction was utilised. The efficacy of various solvents varied.

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# POTASSIUM STATUS OF SOILS OF WESTERN INDIA--II

## FIXATION OF POTASSIUM

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(With two Text-figures)

WHENEVER potassium in the form of a fertilizer salt is applied to soils, it dissolves shortly afterwards in the soil solution and may be absorbed by growing plants and may be partly leached. A major portion enters the soil by base exchange reactions in replaceable form. There is evidence also to show that some quantity of potassium is fixed. N. J. Volk [1934] showed that alternate wetting and drying induces greater fixation than when soils are kept in moist condition. G. W. Volk [1938] tested a number of minerals and found that bentonite fixed the maximum amount of potassium. A similar observation was made by Truog and Jones [1938]. Joffe and Kolodny [1938] observed that fixation of potassium resulted in a decrease in the exchange capacity of the fixed system. Blume and Purvis [1939] found that limed soils fixed more potassium than unlimed soils. De Turk *et. al.*, [1943] reported that the amounts of potassium fixed in moist storage varied with particle size and anion. Joffe and Levine [1947] obtained linear relation between the amount of potassium entering the exchange complex and the amount of potassium fixed. Stanford [1947] showed that ammonium and potassium are fixed by similar mechanism in soils. Similar conclusion was drawn by Bower [1950] too. Wiklander [1950] found that fixation was affected by the kind of cations in the exchange complex. Mortland and Giesking [1951] showed from X-ray diffraction studies that montmorillonitic clays were changed to mica-like minerals during fixation. Wear and White [1951] presented the hypothesis that the difference in the amounts of potassium fixed by different minerals is due to different attractive forces in the crystal lattice. York *et. al.*, [1953] observed that fixation increased in direct relation to increase in pH. and that fixation had no relation to increased microbial activity. In the present investigation potassium fixation studies have been carried in moist condition with *goradu*, *kiari* and black cotton soils. The mechanical composition of these soils is given in Table I.

TABLE I

*Percentage mechanical composition of goradu, kiari and black cotton soils (oven-dry basis)*

Soil fraction	<i>Goradu</i>	<i>Kiari</i>	Black cotton
Coarse sand	0.25	0.43	1.36
Fine sand	84.70	53.37	24.85
Silt	5.22	33.93	47.21
Clay	9.83	12.27	26.58
Moisture in airdry sample	1.22	3.52	8.20

*Fixation technique*

Two kilogram of the soil was stirred with KCl added in the form of a solution so that the whole mass was of semi-liquid consistency. It was then brought at room temperature to optimum moisture for crop growth (40 per cent of water holding capacity) and stored at room temperature in covered jars. From time to time water was added to keep the moisture content constant throughout the experiment. At the end of a certain period varying from 30 to 370 days, a portion was taken out and dried at room temperature. A portion of the soil after air-drying was leached with normal ammonium acetate and the amount of potassium in the leachate was determined. If this quantity is deducted from the amount of potassium added as solution and that present in the soil in exchangeable form before treatment, the difference gives the value of potassium fixed. Results are given in Table II.

TABLE II

*Potassium fixation in goradu soil*

Amount of KCl m.e./100 gm. soil	Fixation m.e./100 gm. soil								p.c. fixation during 30 days of maximum fixation
	period in days								
	30	60	90	120	150	210	280	370	
0-00	0-010	..	0-006	..	..	0-012	..	-0-009	..
1-25	0-540	0-552	0-558	0-573	0-575	0-578	0-575	0-583	92-6
2-50	0-995	1-055	1-180	1-275	1-285	1-307	1-261	1-250	76-1
5-00	1-445	1-520	1-571	1-687	1-669	1-673	1-669	1-670	85-6
10-00	1-683	1-812	2-151	2-180	2-287	2-280	2-380	2-400	70-1
15-00	2-164	2-306	2-785	2-753	2-998	2-998	2-950	3-030	71-4
20-00	2-162	2-234	2-711	2-750	2-778	2-955	2-953	3-038	71-2
25-00	2-144	2-282	2-777	2-712	2-827	3-047	3-080	3-010	69-6

## RESULTS AND DISCUSSIONS

*Effect of time of contact and concentration on fixation*

Two significant facts are prominently shown in this set of experiments. At low concentration of the applied salt, fixation amounting to almost 90 per cent of the maximum quantity of potassium fixed, takes place during the first 30 days while at high concentration this percentage drops down to 70. It can still be said that the major amount of fixation takes place during the first month. If no potassium is added, there is an equilibrium between the fixed and exchangeable potassium in the soil. As the concentration of the added potassium salt solution increases, there is an increase in fixation. This increase, however, is not linear. It increases rapidly at first but soon decreases. At concentrations greater than 15 m.e. per 100 gm. soil, there is no further effect of concentration on fixation. Apparently complete fixation takes place when the soil is kept in moist contact with 15 m.e. potassium per 100 gm. soil for a period of 210 days. In this connection, it may be pointed out that Stanford [1948] got little fixation in illite and none in bentonite in moist state. Volk's [1934] observations are that minerals of the expanding lattice type do not fix potassium except on alternate wetting and drying at 70°C and that fixation in moist condition is at most slow. But Blume and Purvis [1939], Allaway and Pierre [1939], Hoover [1944], De Turk *et. al.* [1943] and Bower [1950] have obtained good amount of fixation in moist condition. The present results show that appreciable amounts of potassium are fixed even in moist storage in the case of all the three soils studied. Black cotton soil fixes more than 50 per cent, *kiari* about 25 per cent and *goradu* soil about 14 per cent of the applied potassium in one month (Table III).

TABLE III

*Fixation of potassium in goradu, kiari and black cotton soils*

Amount of K added m.e./100 gm. soil	Soil	Base exchange capacity m.e./100 gm.	Fixation m.e. per 100 gm. soil			
			period in days			
			30	90	210	370
15-00	<i>Goradu</i>	9-91	2-164	2-785	2-998	3-030
15-00	<i>Kiari</i>	29-88	5-262	5-430	5-715	5-750
15-00	Black cotton	50-00	7-775	7-837	8-093	8-058

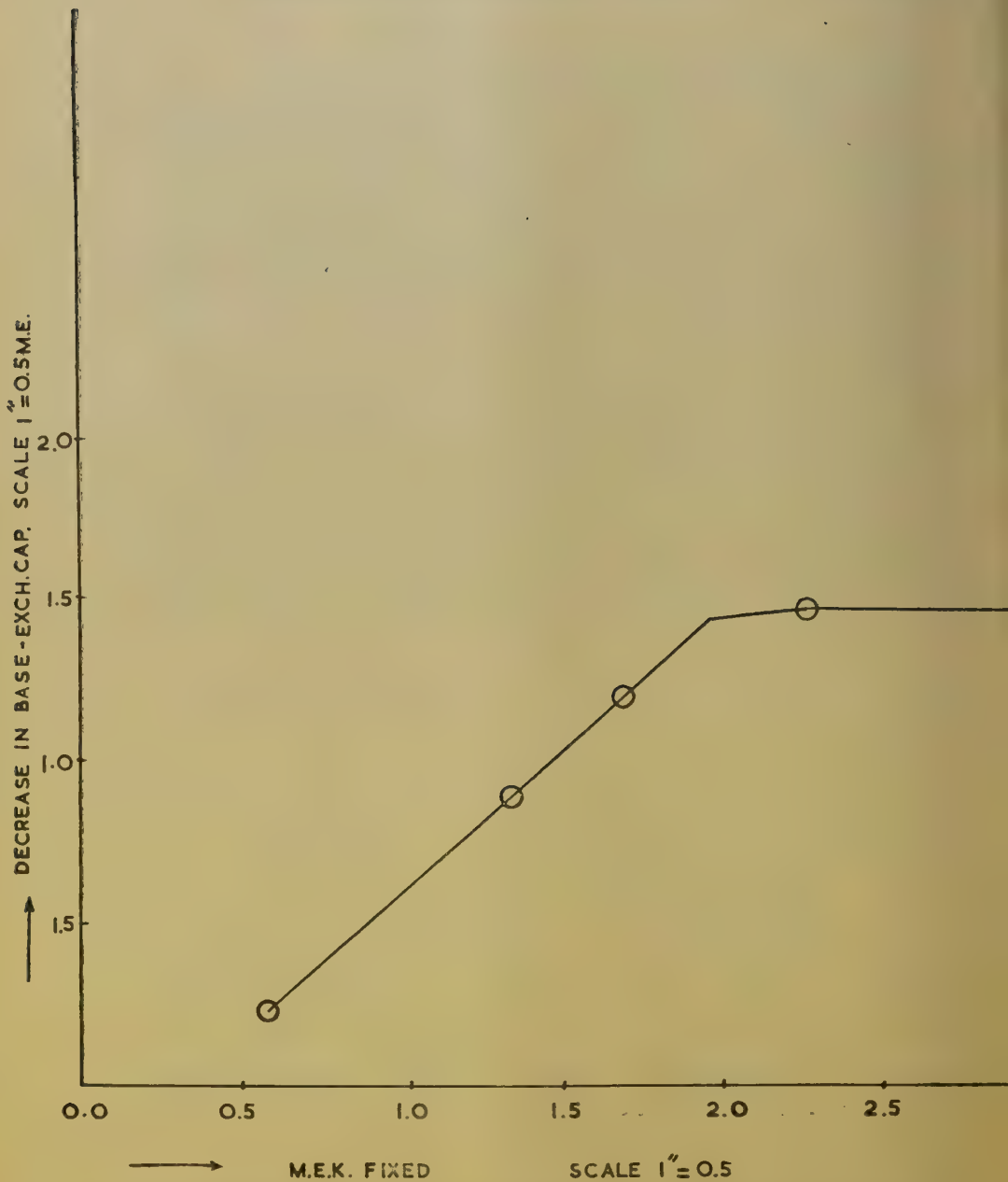


FIG. 1. Relation between Fixation of K. and Decrease in Base-Exchange Capacity of *Goradu* Soil



*Fixation of potassium and base exchange capacity*

Hogland and Martin [1933], Peterson and Jennings [1938], Truog and Jones [1938] and Joffe and Levine [1947] observed that fixation of potassium decreased the base exchange capacities of soils. To get an idea regarding the relationship existing between the base exchange capacity and fixation in *goradu*, *kiari* and black cotton soils, the exchange capacities were determined before and after fixation. The period of fixation was kept constant at 210 days, as maximum fixation then takes place. The soils were analysed for water soluble and exchangeable potassium contents. Water soluble potassium was determined by taking, soil : water ratio 1 : 10. Results are given in Table IV.

TABLE IV

*Relation between potassium fixation and base exchange capacity*

Soil	Amount of K. applied m.e./100 gm.	Water soluble K. m.e./100 gm.	K. in exchange complex m.e./100 gm.	Exchangeable K. m.e./100 gm.	K. fixed m.e./100 gm.	Exchange capacity without K. treatment m.e./100 gm.	Exchange capacity of K. treated soil m.e./100 gm.	Decrease in exchange capacity m.e./100 gm.	Decrease in base exchange capacity K. fixed
<i>Goradu</i>	0.00	0.060	..	0.465	..	10.21	..	..	..
do.	1.25	0.440	1.335	0.757	0.573	10.21	10.01	0.20	0.346
do.	2.50	0.720	2.305	0.998	1.307	10.21	9.33	0.88	0.673
do.	5.00	2.133	3.392	1.712	1.673	10.21	9.01	1.20	0.717
do.	10.00	5.000	5.525	3.245	2.280	10.21	8.74	1.47	0.645
do.	15.00	8.480	7.045	4.047	2.998	10.21	8.76	1.45	0.484
do.	20.00	12.505	8.020	5.025	2.995	10.21	8.82	1.39	0.464
do.	25.00	17.460	8.065	5.018	3.047	10.21	8.70	1.51	0.496
<i>Kiari</i>	0.00	0.106	..	0.758	..	29.85	..	..	..
do.	15.00	4.620	11.244	5.529	5.715	29.85	26.52	3.33	0.583
Black cotton	0.00	0.090	..	1.183	..	49.80	..	..	..
do.	15.00	2.500	13.773	5.680	8.093	49.80	44.71	5.09	0.629

It can be seen that as the concentration of the salt increases, there is a progressive decrease in the base exchange capacity when fixation takes place. But there is no equivalence between the decrease in base exchange capacity and the amount fixed [Truog and Jones, *loc. cit.*]. The relationship is represented graphically in Fig. 1. It is evident that up to 2 m.e. fixation per 100 gm. soil, the relationship between fixation and decrease in base exchange capacity is linear. Beyond that value the base exchange capacity remains practically steady. Similarly when the concentrations of the added salt exceeds 15 m.e. there is no further reduction in the base exchange capacity or increase in fixation.

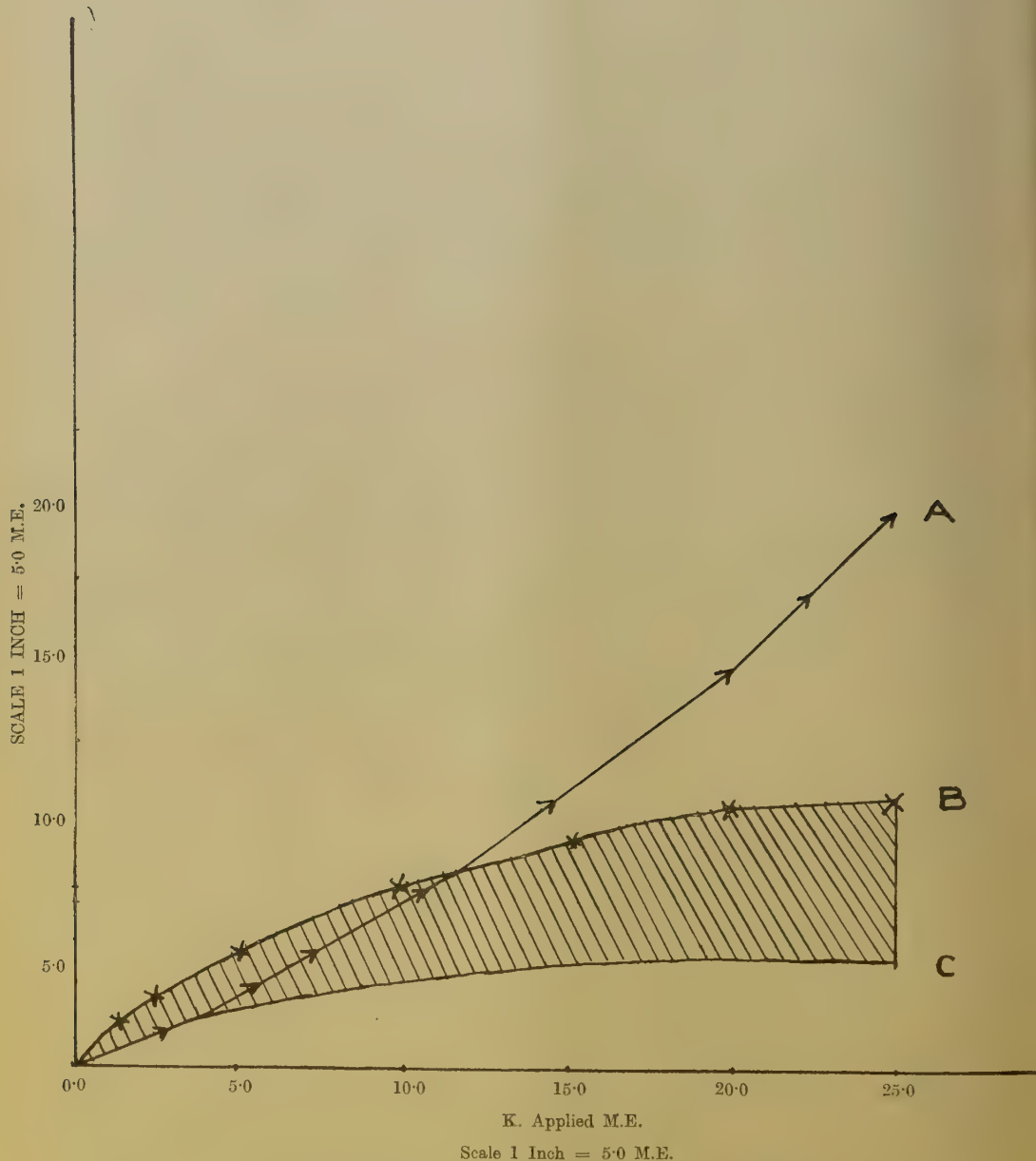


FIG. 2. Relation between A. Water-Soluble-K and Applied K.

B. Exchange-Complex-K „ „ „

C. Fixation of K „ „ „

Fig. 2 shows three curves : (i) water soluble K against applied K, (ii) K in exchange complex against applied K and (iii) fixed K against applied K. There is a gradual rise in water soluble potassium as the amount of applied potassium is increased. But the potassium in exchange complex does not continue to increase and it remains constant after 17.50 m.e. of applied potassium. The curves showing water soluble potassium and exchange complex potassium meet at a point which denotes 11.33 m.e. of the applied potassium. This indicates that up to this concentration, a higher fraction of the added salt will be retained by the exchange complex. Beyond this point a higher fraction of the added salt will remain in water soluble form. Under such circumstances, there will be greater loss by leaching. Actually the two curves form a loop which indicates the area where the amount of exchange complex exceeds the water soluble fraction.

#### *Effect of anion on fixation of potassium*

Fixation was carried out by applying KCl,  $K_2SO_4$  and  $KH_2PO_4$ . Samples were taken after 30, 90, 150 and 280 days and analysed. The results are given in Table V.

TABLE V

#### *Effect of anions on fixation of potassium*

Salt	Amount of K applied m.e./100gm.	Fixation m.e./100 gm. soil			
		period in days			
		30	90	150	280
KCl	15.00	2.164	2.785	2.998	2.980
$K_2SO_4$	15.00	2.143	2.778	2.885	2.973
$KH_2PO_4$	15.00	2.728	3.375	3.633	3.600

There is practically no difference in fixation in the case of two highly dissociating salts KCl and  $K_2SO_4$  but fixation is greater in the presence of phosphate ion. Hoagland and Martin [1933] reported that the nature of anions exerts no influence on potassium fixation. The salts used by them were highly dissociating salts. Joffe and Levine [1947] got greater fixation with acetate than with chloride. Hoover [1944] reported that more potassium was fixed when KCl was used than when  $KH_2PO_4$  was used with a kaolinitic soil whereas De Turk *et al.*, [1943] got greater fixation with  $K_2HPO_4$  than with KCl.

*Fixation of potassium in soil saturated with other cations*

In the study of potassium fixation, it is of practical as well as theoretical interest to know as to what extent the cations absorbed by the exchange complex influence the fixation of subsequently added potassium. Goradu soil was saturated with  $H^+$ ,  $NH_4^+CA^{++}$ ,  $Mg^{++}$  and  $Na^+$  and fixation carried out as before. The results are given in Table VI.

TABLE VI

*Fixation of potassium in goradu soil saturated with different cations*

Amount of added KCl m.e./100 gm.	Fixation of K.m.e./100 gm. soil saturated with					
	$H^+$	$NH_4^+$	$Ca^{++}$	$Mg^{++}$	$Na^+$	Mixed cations
2.50	0.513	0.610	0.955	1.008	1.112	0.995
5.00	0.843	0.895	1.453	1.505	1.767	1.455
15.00	1.843	1.996	2.643	2.515	2.705	2.164

Table VI shows that H-soil has the least fixing power and Na-soil the greatest for all concentrations of applied KCl.  $NH_4$ -soil has a slightly higher fixing capacity than H-soil but Ca- and Mg-soil have much greater fixing capacities than both H- and  $NH_4$ -soils. In the order of their fixing power the cations can be arranged as  $Na^+ > Mg^{++} > Ca^{++} > NH_4^+ > H^+$ . Joffe and Levine [1939] working with Montalto clay have found that Na-clay fixes less potassium than H- and Ca-clays. The reason they have advanced is that the large envelope of hydration which surrounds  $Na^+$  is responsible for such a phenomenon. Wiklander [1950] on the contrary has obtained maximum fixation of radioactive potassium in Na-saturated clays prepared by a long process of heating clay with NaCl solution for 21 days at  $65^\circ C - 70^\circ C$  and changing the solution every two days. He believes that by this long process the fixed potassium is replaced and the clay becomes highly saturated with Na ions which are able to admit potassium ions readily. Page and Bayer [1940] have concluded that for expanding minerals there is an intimate relation between ionic volume and fixation. Cations in the base exchange complex of the soil having a smaller diameter facilitate fixation to a larger extent. According to Pauling [1930], the ionic diameters of  $NH_4^+$ ,  $K^+$ ,  $Ca^{++}$ ,  $Na^+$  and  $Mg^{++}$  are in descending order and  $Ba^{++}$  and  $NH_4^+$  have equal diameters. Wiklander [1950], however, found that  $Ba^{++}$  induced 50 times greater fixation than  $NH_4^+$ . He therefore, concluded that the properties other than the ion volume play an important part in facilitating or preventing fixation of another ion and possibly, the pH of the clay, the diameter of the cation and its chemical properties are all responsible. The results obtained in the present work show that fixation in soils saturated with different cations generally follows the pattern suggested by Page and Bayer [1940].

*Fixation of potassium in the presence of other cations*

The competitive action of other cations on the fixation of potassium has been studied by Chapman and Kelley [1930], Peterson and Jennings [1938] and Joffe and Levine [1939]. They have reported that the presence of  $\text{CaCl}_2$  exerts a depressing effect on the fixation of potassium. Bower [1950] has found that in the presence of  $\text{NH}_4\text{Cl}$ , the fixation of potassium is inversely proportional to the quantity of the ammonium salt. The effect of  $\text{NH}_4^+$ ,  $\text{Ca}^{++}$ ,  $\text{Mg}^{++}$  and  $\text{Na}^+$  on the fixation of potassium on *goradu* soil has been studied here. Results are given in Table VII.

TABLE VII

*Fixation of potassium in presence of other ions*

Amount of cations added m.e./100 gm. $\text{K}^{++}$ other cations	Fixations in presence of $\text{NH}_4^+$ m.e./100 gm.	Fixation in presence of $\text{Ca}^{++}$ m.e./100 gm.	Fixation in presence of $\text{Mg}^{++}$ m.e./100 gm.	Fixation in presence of $\text{Na}^+$ m.e./100 gm.
15+5	1.695	1.838	1.888	1.933
15+0	2.164	2.164	2.164	2.164
10+10	0.965	1.198	1.211	1.308
10+0	1.683	1.683	1.683	1.683
5+15	0.385	0.613	0.613	0.738
5+0	1.445	1.445	1.445	1.445

It is seen that reduction in fixation takes place in all cases. The reduction in fixation is 21.2 per cent when the ratio of  $\text{K}^+ : \text{NH}_4^+$  is 3 : 1, 42.7 per cent when it is 1 : 1 and 73.4 per cent when it is 1 : 3. Thus the percentage reduction in potassium fixation becomes greater as the ratio  $\text{K}^+ : \text{NH}_4^+$  widens. The corresponding reductions are less when  $\text{Ca}^{++}$  is the competing ion, being 10.5, 28.8 and 57.6 per cent respectively. With  $\text{Mg}^{++}$  and  $\text{Na}^+$ , the corresponding reductions are 12.8, 28.0, 57.6 and 10.7, 22.3, 48.9 per cent respectively. A reduction in fixation is to be expected when a mixture of cations is applied in view of the fact that other cations compete with  $\text{K}^+$  for exchange positions. But their competitive abilities in reducing fixation are different. The order is  $\text{NH}_4^+ > \text{Ca}^{++} > \text{Mg}^{++} > \text{Na}^+$ .

*Fixation of potassium in goradu soil separates*

The properties of the soil vary with the physical and chemical properties of soil separates, and on the whole, their relative importance increases with decrease in particle size, reaching a maximum in the colloidal fraction. Ogg and Hendrick [1920] showed that the fine silt and silt fractions of some Scottish soils had an appreciable capacity for cation absorption. Russel [1937] stated that such properties of the soil are connected more closely with the size of the soil particles than with



their chemical properties. Hosking and Piper [1938], Pathak *et. al.*, [1949], Burwill [1938] and Hosking [1948] have adduced sufficient evidence to show that base exchange is not entirely a physical phenomenon but that it also depends upon the clay minerals which are also present in the coarser fractions of the soil. If the coarser fractions of the soil affect the base exchange, they should also affect the phenomenon of fixation which takes place through the medium of base exchange reactions. It was, therefore, thought interesting to investigate the fixation of potassium by different fractions of *goradu* soil. For this purpose 500 gm. *goradu* soil was treated thoroughly with hydrogen peroxide and transferred to bottles and dispersed by agitating in an end over end shaker for 200 hours without the addition of any dispersing agent. It was then transferred to a 20 litre carboy and made up to about 19 litres with water. The time for particles to fall a distance of 10 cm. was calculated from Stoke's law. The carboy was shaken and after the calculated time, the suspension in upper 10 cm. layer was siphoned off by means of a tube curved upward at the bottom, the opening of which extended 10 cm. below the surface of the liquid. The contents of the carboy were vigorously shaken and again after specified time the contents were siphoned off. The contents were then transferred to a tall jar and siphoned off as before. This was repeated. The contents were then diluted and agitated in the mechanical shaker for five hours. The same process of siphoning was repeated. In this way mechanical shaking was done 20 times to separate the clay having diameter less than 0.001 mm. Other particles were also separated from the remaining portions and their base exchange capacities, exchangeable potassium and fixation of potassium determined. Results are given in Table VIII.

TABLE VIII  
*Potassium fixation in goradu soil separates*

Diameter of particles	Name	Per cent in soil (oven dry basis)	Exch. K. m.e./100 gm.	Base exch. capacity m.e./100 gm.	Per cent contributed by the separate to base exchange capacity	Fixation of K.m.e./100 gm. (2.5 m.e. K/100 gm. applied)
<—0.001	Clay	8.44	6.449	66.50	54.09	2.201
0.001—0.002	Clay	1.38	5.820	62.00	8.22	2.105
0.002—0.004	Fine silt	1.70	1.856	38.00	6.20	1.980
0.004—0.006	Fine silt	0.89	1.629	33.10	2.83	1.818
0.006—0.008	Fine silt	0.70	1.023	20.02	1.36	1.728
0.008—0.01	Fine silt	0.26	0.833	16.50	0.42	1.602
0.01 —0.02	Silt	1.67	0.606	14.50	2.34	1.702
0.02 —0.04	Very fine sand	5.11	0.379	8.10	3.99	1.270
0.04 —0.05	Very fine sand	3.06	0.341	6.51	1.92	1.223
0.05 —0.2	Fine sand	76.53	0.189	2.53	18.63	0.330
0.2 —2.0	Coarse sand	0.26				

It is seen that the exchangeable potassium and the base exchange capacity increase with decreasing size of the particles. Even fine sand has appreciable base exchange capacity and exchangeable potassium. Commenting on the role of sand in supplying available nutrients, Kunin and Robbins [1944] emphasise the fact that certain soil fractions, large enough to be classed as sand, may have an important role in the supply of nutrient cations to plants. The increase in exchange capacity with the decrease in size of the particles is considered as being due to an increase in the total surface and hence due to a greater number of exchange points [Whitt and Bayer, 1937]. Bray [1937] attributes such an increase in base exchange capacity to a variation of the minerals rather than to a decreased particle size itself.

The fixation of potassium increases with the decreasing size of the particles. The fixation increases with the increase in base exchange capacity also. Silt has more than 60 per cent of the fixing capacity of clay and sand about 10 per cent. It is noteworthy that though sand has the lowest potassium fixing power, it is not a negligible figure. This is particularly so because it constitutes more than 80 per cent of the entire soil mass. Sand thus plays an important part in holding tenaciously any applied potassium in a fixed form in soil and in preventing leaching losses. Barshad [1951] has observed that in some soils coarser fractions also fix up potassium.

#### SUMMARY

Fixation of potassium in *goradu*, *kiari* and black cotton soils of Western India has been studied. It increases with increase in concentration of the applied potassium per 100 gm. soil. Then it remains practically constant. Fixation also increases with increase in the time of contact. Equilibrium is reached in about 7 months. Fixation of potassium in *goradu*, *kiari* and black cotton soils is in the increasing order. A decrease in the base exchange capacity occurs when fixation takes place but there is no equivalence between the two. A larger fraction of the added potassium is retained by the exchange complex upto 11.33 m.e. applied potassium per 100 gm. soil. Beyond this point a larger fraction is in water soluble state. Fixation from  $\text{KH}_2\text{PO}_4$  is greater than from  $\text{KCl}$  and  $\text{K}_2\text{SO}_4$  but there is no difference in the fixation by these two. *Goradu* soil saturated with different ions has the potassium fixing power in the order  $\text{Na}^+ > \text{Mg}^{++} > \text{Ca}^{++} > \text{NH}_4^+ > \text{H}^+$ . The presence of other ions in solution reduces the fixation of potassium. The order of the competitive abilities of ions in reducing fixation is  $\text{NH}_4^+ > \text{Ca}^{++} > \text{Mg}^{++} > \text{Na}^+$ . Fixation increases with increase in *pH*. Coarser fractions of the soil also contribute to the total base exchange capacity and fixation of potassium.

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## POTASSIUM STATUS OF SOILS OF WESTERN INDIA-III

### RELEASE OF NON-EXCHANGEABLE POTASSIUM IN SOILS

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IT is a current belief that potassium taken up by a crop is either from soil solution or that which is in exchangeable form together with a practically negligible quantity assumed to be made available as a result of weathering of primary minerals. This concept of the potassium supplying power of the soil is by no means adequate to explain the sustained potassium fertility of many soils under conditions of continuous cropping. Lamb [1935], and Bartholomew and Jenssen [1931] reported that plants can reduce with difficulty the amount of exchangeable potassium in the soil below 2.5 mg. per 100 gm. At this stage the plant depends mainly on the non-exchangeable potassium for its nutrition [Sen *et al.*, 1949]. Martin [1929], Fraps [1929], Gedroiz [1931], Hoagland and Martin [1933], and Abel and Magistad [1935] demonstrated that some soils release substantial quantities of non-exchangeable potassium to growing plants. Attoe and Truog [1946] found in pot tests that maize and oats were able to grow on soils from which all exchangeable potassium had been removed whilst Oslen and Shaw [1943] obtained similar results using Neubauer seedling tests on silt fractions leached free of exchangeable potassium. Chandler, Peech and Chang [1945] found upon continuous cropping of soils with clover that in spite of the ability of clover to take large amounts of non-exchangeable potassium, the yield was closely associated with exchangeable potassium. A similar conclusion was arrived at by Bear, Prince and Malcolm [1944]. Evans and Attoe [1948] observed that liming of acid soils repressed the amount of total and non-exchangeable potassium removed by oats. Stewart and Volk [1946], working on Alabama soils, reported that on an average, two-thirds of the potassium used by the plants came from forms that were non-exchangeable. Ayres [1949], working on the release of potassium in Hawaiian sugarcane soils, found that the release of potassium upon cropping, averaged approximately 700 lb. per acre-foot of soil for seven crops of the Sudan and Panicum grasses. Ayres, Takashi and Kanehiro [1946] in a 4½-year field study with Napier grass, reported release of 3,400 to 4,200 lb. of non-exchangeable potassium per acre. Breland *et al.*, [1950], from their study of Indiana soils, found no relation between the potassium removed by the crops and the exchangeable potassium present in the soil, nor between the total potassium content of the soils and their potassium releasing power. Pearson [1952] also reported that there was no apparent relationship between the capacity of the soils to release potassium either from non-exchangeable forms or from the total potassium content and its distribution among the particle size separates.



The release of non-exchangeable potassium is not necessarily conditional upon root activity. This has been shown by Bray and De Turk [1938], Wood and De Turk [1942], Allaway and Pierre [1939], York and Rogers [1947], Abel and Magistad [1935] and Bartholomew and Jenssen [1931], who observed varying degrees of release of non-exchangeable potassium upon moist storage of soils following removal of exchangeable potassium by chemical means. Fixed potassium resulting from additions of potassium salts to soils was released by the same process according to the studies of De Turk, Wood and Bray [1943]. Ayres [1949] studied the rates of release in soils on moist storage, on electrodialysis and on cropping, and found that the release of potassium upon moist storage was much less than that upon cropping.

Because of the ability of the plants to absorb non-exchangeable potassium Schachtschabel [1941] considered that biological methods of assessing availability such as the Neubauer seedling method, should be used to obtain reliable results. Quantities of potassium obtained by boiling the soil with 1N  $\text{HNO}_3$  for 10 minutes [De Turk *et al.*, 1943, Pratt, 1951], with 0.5N HCl for one hour [Attoe and Truog 1946], treatment with 1N HCl [Ayres, 1949] and extraction with citric acid [Sen *et al.*, 1949] have been shown to represent quantities of potassium available to plants during cropping. Reitemeier *et al.* [1947] and Ayres [1949] reported that the rate of solution of potassium during electrodialysis was related to the quantities converted from non-exchangeable to readily available form during cropping. Recently Schmitz and Pratt [1953] reported that the combination of exchangeable potassium and that released from non-exchangeable form to nitric acid gave a more accurate index to potassium removal by crops and to uptake percentage than did any other single factor.

The nature of the solution employed and also the nature of the complementary cations influenced markedly the rate of release of non-exchangeable potassium. Some investigators have studied the release of potassium in soils in moist storage when the predominant cation present in the exchange positions was either  $\text{H}^+$  or  $\text{Ca}^{++}$  [Ayres 1949; De Turk *et al.*, 1943]. It is believed that the  $\text{NH}_4^+$  exerts a pronounced blocking effect on the conversion of non-exchangeable potassium into exchangeable form [Peech, 1948]. This article describes a study of the release of potassium from *goradu*, *kiari* and black cotton soils under different conditions. For this purpose  $\text{H}^+$ ,  $\text{NH}_4^+$ ,  $\text{Ca}^{++}$  and  $\text{Na}^+$  saturated soils have been prepared. A study has also been made of the release of the potassium in *goradu* soil upon continuous cropping with *bajri* (*Pennisetum typhoideum*), the main cereal crop of the Kaira district.

#### *Release of non-exchangeable potassium in goradu, kiari and black cotton soils*

Soil was treated with potassium chloride solution; moisture was maintained at 40 per cent of the water holding capacity and fixation allowed to take place. At the end of definite periods (Tables I and II) a portion was taken out and soluble and exchangeable potassium leached out with normal ammonium acetate. The excess of acetate was washed out with 60 per cent neutral alcohol. The release of potassium



during different periods was studied in soils completely leached of soluble and exchangeable potassium. The leached soil was kept at room temperature in moist storage for the required period, and the potassium released during the period of storage was estimated by ammonium acetate extraction and the soil washed with alcohol.

The soil was kept for a period of one month and was leached. The leached soil was kept for successive periods of 2, 3, 4, 5 and 3 months and was leached every time at the end of the periods, so that during the total period of  $(1+2+3+4+5+3)=18$  months, it was leached six times. The figures given in Table I refer to the amount of potassium released in the soil at the end of the storage period.

TABLE I

*Release of non-exchangeable potassium in soils having a fixation period of one month*

Soil	Previous treatment KCl m. e./ 100 gm. soil	m. e. of K released per 100 gm. soil after successive periods in months						Total release m. e./ 100 gm. soil in 18 months	lb. per acre
		1	2	3	4	5	3		
<i>Goradu</i>	0-00	0-120	0-050	0-040	0-052	0-029	0-030	0-321	250
	1-25	0-173	0-075	0-055	0-030	0-035	0-021	0-389	303
	2-50	0-203	0-089	0-050	0-040	0-040	0-035	0-457	356
	5-00	0-225	0-100	0-060	0-050	0-040	0-040	0-515	402
	10-00	0-221	0-080	0-050	0-060	0-050	0-041	0-502	392
	15-00	0-230	0-105	0-065	0-070	0-051	0-038	0-559	436
	20-00	0-228	0-104	0-080	0-061	0-048	0-040	0-561	438
<i>Kiari</i>	25-00	0-231	0-105	0-070	0-061	0-055	0-045	0-567	442
	0-00	0-168	0-072	0-075	0-075	0-055	0-045	0-490	382
Black cotton	15-00	0-300	0-120	0-110	0-088	0-075	0-065	0-758	591
	0-00	0-173	0-105	0-105	0-085	0-070	0-069	0-607	473
	15-00	0-443	0-200	0-120	0-125	0-100	0-080	1-068	833

Tables I and II give the results of the release of potassium in *goradu*, *kiari* and black cotton soils. *Goradu* soil treated with 1-25 m.e. potassium salt released in 18 months by six successive leachings 0-389 m.e. potassium. This amounts to 72 per cent of the amount of potassium fixed. [Mehta and Shah *vide* Part II of this series.] Also, as the amount of KCl used in fixation treatment increases, the amount

of potassium released also increases. The release of potassium almost runs parallel to fixation inasmuch as greater quantities of potassium are released when greater quantities of potassium are fixed. Though the actual amount of potassium released increases with fixation, a smaller fraction of the amount fixed is released with increasing fixation. It is not possible to say at this stage, whether this release is from the potassium that was fixed. According to De Turk *et al.*, [1943], the fixed potassium merges with other potassium present in the colloid complex and is present in the same kind of physicochemical relationship.

The *kiari* and black cotton soils, which fixed greater quantities, also released greater quantities of potassium, amounting to about 13 per cent of the amount fixed in both the cases (potassium applied for fixation, 15 m.e. per 100 gm. soil). *Goradu* soil under similar conditions released about 18 per cent of fixed potassium. *Goradu* soil has a greater power of release of potassium after fixation than *kiari* and black cotton soils. In spite of this the actual release in *kiari* and black cotton soils is much greater, being 36 and 90 per cent greater than similarly treated *goradu* soil. The soils to which no potassium was initially added also released potassium. It will be seen that continuous release occurred throughout the period of storage. Release was rapid in the initial period, but later it slowed down even though the soils were kept for longer periods. Release of potassium, thus, is not a linear function of time of storage. It was expected that the release, obtained from the soils which were allowed to fix potassium for a longer time, would be greater. Release of potassium was, therefore, determined in soils which had a fixation period of seven months (Table II). It will be seen that there is a small increase in the release of potassium in all the three soils, as expected.

TABLE II

*Release of non-exchangeable potassium in soils having a fixation period of seven months*

Soil	Previous treatment KCl m. e./ 100 gm. soil	m. e. of K <sub>2</sub> O released per 100 gm. soil after successive periods in months						Total m. e. 100 gm. soil in 18 months	lb. per acre
		1	2	3	4	5	6		
<i>Goradu</i>	0-00	0-128	0-053	0-070	0-068	0-035	0-030	0-384	229
	1-25	0-198	0-108	0-085	0-075	0-058	0-052	0-576	449
	2-50	0-208	0-128	0-088	0-085	0-065	0-058	0-632	493
	5-00	0-298	0-078	0-110	0-090	0-066	0-065	0-702	548
	10-00	0-308	0-148	0-105	0-090	0-070	0-068	0-789	615
	15-00	0-323	0-153	0-126	0-100	0-075	0-069	0-846	655
	20-00	0-373	0-153	0-105	0-101	0-080	0-085	0-897	699
<i>Kiari</i>	25-00	0-348	0-163	0-110	0-100	0-090	0-085	0-896	698
	0-00	0-140	0-100	0-082	0-085	0-065	0-055	0-527	441
	15-00	0-350	0-165	0-140	0-114	0-110	0-110	0-989	771
Black cotton	0-00	0-195	0-105	0-085	0-112	0-095	0-068	0-600	468
	15-00	0-458	0-220	0-180	0-145	0-110	0-105	1-218	950

When the work was well under way, a point arose regarding the ability of soils, from which potassium was not leached out, to release it from non-exchangeable form. The three soils were, therefore, kept in moist condition as before for a period of 12 months and at intervals of 1, 3, 7 and 12 months (Table III), exchangeable potassium determined by exhaustive leaching with normal ammonium acetate.

TABLE III

*Exchangeable potassium in soils in moist storage for different periods without removal of potassium (m.e./100 gm.)*

Soil	0	1 month	3 months	7 months	12 months
<i>Goradu</i>	0.452	0.461	0.445	0.438	0.460
<i>Kiari</i>	0.748	0.733	0.750	0.760	0.745
Black cotton	0.888	0.900	0.905	0.865	0.880

The results given in Table III show that practically no change takes place in the amount of exchangeable potassium. There is some shift here and there indicating slight release of fixation. Thus it is clear that release takes place after the exchangeable potassium is removed. Ayres [1949] has also shown that non-exchangeable potassium is released when a part of the exchangeable potassium is removed. Such a behaviour lends support to the equilibrium theory suggested by Bartholomew and Jenssen [1931], Hoagland and Martin [1933], and De Turk *et al.*, [1943] that there exists an equilibrium between exchangeable and fixed forms of potassium.

*Release of potassium in dry and moist soils kept in diffused, and direct sunlight*

Attoe [1946] showed that air drying of Wisconsin soils resulted in a release from 4 to 90 per cent of the exchangeable fraction present in the moist soil. Ayres [1949] obtained a small release in some cases and fixation in others by over-drying for seven days. Bray and De Turk [1938] heated soils for six days at 200°C. and made a similar observation. They considered that the treatment did nothing more than facilitating or speeding up the approach to a condition of equilibrium. It was thought interesting to compare the release in *goradu*, *kiari* and black cotton soils on drying and in moist conditions when kept in diffused and direct sunlight. For this purpose these three soils, which had received fixation treatments as described before and from which all soluble and exchangeable potassium was removed, were kept in direct sunlight in the moist and dry conditions and also in diffused light under similar conditions. The results are given in Table IV.

TABLE IV

*Release of potassium in soils in moist and dry conditions when kept in diffused light and in direct sunlight (Previous fixation treatment for seven months)*

Soil	Pre-vious treat-ment- KCl m.c./ 100 gm.	Amount of K released per 100 gm. soil in dry state						Amount of K released per 100 gm. soil in moist state.					
		In diffused light during successive periods (in months)			In direct sunlight during successive periods (in months)			In diffused light during successive periods (in months)			In direct sunlight during successive periods (in months)		
		1	2	Total	1	2	Total	1	2	Total	1	2	Total
		m. e.	m. e.	lb. per acre	m. e.	m. e.	lb. per acre	m. e.	m. e.	lb. per acre	m. e.	m. e.	lb. per acre
<i>Gomuti</i>	0.00	0.140	0.085	0.225	176	0.133	0.095	0.248	189	0.128	0.083	0.191	141
	1.25	0.210	0.115	0.325	254	0.225	0.125	0.350	273	0.189	0.108	0.306	239
	2.50	0.252	0.130	0.382	298	0.250	0.140	0.390	304	0.203	0.128	0.336	262
	5.00	0.300	0.120	0.420	328	0.325	0.150	0.475	371	0.298	0.073	0.371	289
	10.00	0.325	0.140	0.465	363	0.340	0.121	0.461	360	0.308	0.148	0.456	356
	15.00	0.388	0.173	0.561	438	0.395	0.195	0.590	460	0.323	0.153	0.476	371
<i>Kirti</i>	20.00	0.380	0.180	0.560	437	0.390	0.195	0.585	456	0.373	0.153	0.526	410
	25.00	0.385	0.180	0.565	441	0.395	0.192	0.587	458	0.348	0.163	0.511	399
	0.00	0.200	0.125	0.325	254	0.200	0.120	0.320	257	0.140	0.100	0.240	187
	15.00	0.400	0.180	0.580	452	0.465	0.158	0.623	486	0.350	0.165	0.515	402
Black cotton	0.00	0.225	0.126	0.351	274	0.256	0.120	0.376	293	0.195	0.105	0.300	234
	15.00	0.495	0.242	0.737	575	0.501	0.250	0.751	586	0.458	0.220	0.678	529

It is seen that there is greater release in dry soils than in moist ones. In direct sunlight in the dry state, the release is more than that in the diffused light. These tendencies are observed in all the three soils. De Turk *et al.*, [1943] and Ayres [1949] got release in some cases and fixation in others by heating soils from which exchangeable potassium was not removed. In the observations made here, the soils were completely leached with ammonium acetate and hence greater release on drying was expected according to De Turk *et al.*, [1943], who believed that such a procedure facilitated the movement of potassium ions out of the fixed positions.

#### *Release of potassium in H-, Ca-, Na-, and NH<sub>4</sub>- soils*

York and Rogers [1947] reported that the amount of potassium released increases with the increasing Ca-saturation of the exchange complex. Ayres [1949] observed nearly  $2\frac{1}{2}$  times as much release in Ca- as in H- soils. Peech [1948] reported blocking effect of  $\text{NH}_4^+$  in the exchange positions on the release of potassium. H-, Ca-, Na- and  $\text{NH}_4^-$  soils were prepared from K-treated soils and the release of potassium determined in moist soils after two successive leachings at intervals of one and two months. Table V gives the results. The order of release of potassium is  $\text{Na}^+ < \text{Ca}^{++} > \text{H}^+ > \text{NH}_4^+$  for all the three soils.

With increasing amount of fixation during the previous soil treatment, the amount released also increased in all the four cases. The release obtained in the case of Ca- soils was 25 to 40 per cent greater than in the case of H- soils, while Ayres [1949] reported  $2\frac{1}{2}$  times greater release. Though Peech [1948] reported a pronounced blocking effect of  $\text{NH}_4^+$  on the release of potassium, the results obtained in the present study show that fairly large quantities of non-exchangeable potassium are released even by  $\text{NH}_4^-$ -soils.

#### *Release of non-exchangeable potassium in sterilized soils*

Ayres [1949] suggested that the more rapid release of potassium on moist storage of Ca-soils as compared with that of H-soils was possibly due to the associated increase in pH and consequent stimulation of bacterial activity resulting in an enhanced breakdown of organic matter and liberation of potassium. Blume and Purvis [1939] suggested the possibility of a microbiological factor affecting the release of potassium. In order to study how microbial action affects the release of non-exchangeable potassium, the soils which had received previous fixation treatments, were exhaustively leached as before with ammonium acetate and sterilized in autoclave for  $1\frac{1}{2}$  hours at 15 lb. pressure. The soils kept in plugged flasks were allowed to liberate potassium as before and the exchangeable potassium was determined after one month. The leached soil was washed with 60 per cent alcohol



TABLE V  
Release of potassium in H-, Ca-, Na- and  $\text{NH}_4$ -soils having a previous fixation treatment for seven months

Soil	Pre-treatment m. e./ 100 gm.	K released in H-soil in successive periods (in months)				K released in Ca-soil in successive periods (in months)				K released in Na-soil in successive periods (in months)				K released in $\text{NH}_4$ -soil in successive periods (in months)			
		1		2		1		2		1		2		1		2	
		m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre	m. e.	lb. per acre
<i>Granite</i>	0-00	0-179	0-304	0-125	0-304	0-201	0-391	0-190	0-305	0-220	0-400	0-180	0-400	0-128	0-181	0-033	0-141
	1-25	0-228	0-368	0-140	0-368	0-320	0-520	0-200	0-406	0-350	0-570	0-220	0-570	0-108	0-306	0-108	0-239
	2-50	0-288	0-448	0-160	0-448	0-345	0-580	0-215	0-437	0-340	0-587	0-247	0-587	0-208	0-336	0-128	0-262
	5-00	0-305	0-455	0-150	0-455	0-359	0-560	0-210	0-437	0-362	0-613	0-251	0-613	0-298	0-371	0-073	0-289
	10-00	0-340	0-520	0-180	0-520	0-390	0-640	0-250	0-499	0-380	0-670	0-290	0-670	0-308	0-456	0-148	0-336
	15-00	0-390	0-545	0-185	0-545	0-390	0-630	0-240	0-491	0-408	0-693	0-295	0-693	0-323	0-476	0-133	0-371
<i>Kiari</i>	20-00	0-359	0-554	0-105	0-554	0-490	0-745	0-255	0-581	0-450	0-740	0-290	0-740	0-373	0-326	0-153	0-410
	25-00	0-355	0-549	0-194	0-549	0-470	0-731	0-261	0-570	0-500	0-782	0-282	0-782	0-348	0-511	0-168	0-399
	0-00	0-265	0-423	0-158	0-423	0-300	0-505	0-205	0-394	0-315	0-530	0-215	0-530	0-140	0-240	0-100	0-137
	15-00	0-415	0-625	0-210	0-625	0-520	0-770	0-250	0-60	0-515	0-748	0-233	0-748	0-350	0-515	0-165	0-402
Black cotton	0-00	0-290	0-480	0-190	0-480	0-368	0-578	0-210	0-451	0-370	0-598	0-228	0-598	0-195	0-300	0-105	0-231
	15-00	0-515	0-735	0-220	0-735	0-528	0-833	0-305	0-650	0-550	0-860	0-310	0-860	0-458	0-678	0-220	0-529

TABLE VI

*Release of potassium in sterilised soils and in soils with and without organic matter (previous fixation treatment for seven months)*

Soil	Organic matter m.e./ 100 gm. Per cent	Pre- vious treat- ment m.e./ 100 gm. soil	K released in sterilised soil in successive periods (in months)				K released in soils without organic matter in successive periods (in months)				K released in soils without removal of organic matter in successive periods (in months)			
			1	2	Total	lb. per acre	1	2	Total	lb. per acre	1	2	Total	lb. per acre
			m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.	m.e.
<i>Goradu</i>		0.00	0.121	0.088	0.209	163	0.120	0.090	0.210	164	0.128	0.053	0.181	141
		1.25	0.189	0.075	0.264	206	0.198	0.109	0.307	240	0.198	0.108	0.306	239
		2.50	0.208	0.120	0.328	256	0.200	0.120	0.320	250	0.208	0.128	0.336	262
		5.00	0.300	0.118	0.418	326	0.300	0.110	0.410	320	0.298	0.073	0.371	280
	1.12	10.00	0.290	0.125	0.415	324	0.280	0.150	0.430	335	0.308	0.148	0.456	338
		15.00	0.295	0.145	0.440	343	0.235	0.145	0.480	375	0.323	0.153	0.476	371
<i>Kirti</i>		20.00	0.350	0.163	0.513	400	0.360	0.175	0.535	417	0.374	0.153	0.526	410
		25.00	0.360	0.163	0.518	404	0.340	0.160	0.500	390	0.348	0.163	0.511	399
	1.86	0.00	0.165	0.130	0.295	230	0.165	0.128	0.293	229	0.140	0.100	0.240	187
Black cotton		15.00	0.372	0.148	0.520	406	0.365	0.160	0.525	410	0.350	0.165	0.515	402
	2.12	0.00	0.180	0.100	0.280	218	0.205	0.115	0.320	250	0.195	0.105	0.300	234
		15.00	0.432	0.210	0.642	501	0.450	0.230	0.680	530	0.458	0.220	0.678	529

and sterilised again. The amount of potassium released after two months was determined. Results given in Table VI, show that even when the soils were sterilised, there was a fairly good amount of release of non-exchangeable potassium. A comparison of the results with those in unsterilised soils shows that microbiological action cannot be a factor responsible for the release of non-exchangeable potassium.

#### *Effect of organic matter on the release of non-exchangeable potassium*

Bartholomew [1928], Murphy [1934] and Walker as reported by Worsham and Sturgis [1941], reported release of non-exchangeable potassium in soils resulting from the decomposition of organic matter. Hoagland and Martin [1933] were not inclined to assign to organic matter any influence on the level of released potassium other than that resulting from the liberation of potassium contained in the organic matter itself. In order to see whether there is any effect of organic matter on the release of non-exchangeable potassium, *goradu*, *kiari* and black cotton soils, having 1.12, 1.86 and 2.12 per cent organic matter respectively, were leached with ammonium acetate. Organic matter was oxidized by repeated  $H_2O_2$  treatment and soils kept in moist storage. Results given in Table VI for the release after two successive leachings at the end of one and two months show that there is only a small increase in the release of non-exchangeable potassium due to the removal of organic matter. If the removal of organic matter affects the release of potassium, the small increase obtained in the present case may be due to the small amount of organic matter in the soils themselves or very small amount of potassium unextractable by ammonium acetate in the organic matter of the soils studied.

#### *Release of potassium on cropping*

The chemical method of determining the release of non-exchangeable potassium is useful in estimating the potential supplying power of soils but it does not simulate the release of non-exchangeable potassium taking place during the growth of plants, firstly because the exchangeable potassium content is not likely to be reduced to nothing during crop growth as in the case of moist storage method followed and secondly because the release of potassium is not only a function of the supplying power of the soil but also a function of the feeding power of the plant. It was, therefore, decided to study the release of non-exchangeable potassium in *goradu* soil by continuous cropping of *bajri* (*Pennisetum typhoideum*).

Six 4-lb. pots were each filled with 1.2 kg. of *goradu* soil and 20 seeds of *bajri* were sown in each pot. When the plants were 10 days old they were thinned to six plants. All fertilizer needs except potassium were satisfied by giving 0.1 gm. ammonium nitrate and ammonium phosphate each and 10 c.c. of solution containing 0.25 p.p.m. each boron, manganese and zinc, 0.50 p.p.m. iron, 0.10 p.p.m. copper and 0.015 p.p.m. molybdenum [Evans *et al.*, 1950]. All the chemicals used were of B.D.H. 'analar' quality. The crops were harvested before the onset of the milk stage each time. After harvesting, the soil was thoroughly mixed and exchangeable potassium determined. *Bajri* was sown again in all the six pots and harvested as before. In this way six successive crops of *bajri* were taken. The dates of sowing and harvest and exchangeable potassium at the end of each harvest are given in Table VII.

TABLE VII

*Release of potassium in goradu soil on continuous cropping of bajri*

Crop Number	Date of sowing	Date of harvest	Exch. K m.e./100 gm.		Exch. K lb. per acre		Yield gm. (oven dry)	Per cent K in plants	K taken by plants (m.e.)	K taken by plants (lb. per acre) (c)	K removed by plant + remaining in exch. form (lb. per acre) (b+c-a)	K supplied from non-exch. form of soil taken up by plant (b+c-a)	Non-exch. K as p.c. of total K taken up by plant	Per cent reduction in exch. K due to cropping
			at sowing	at harvest	at sowing (a)	at harvest (b)								
I	11-3-50	10-6-50	0.425	0.365	332	285	24.8	2.44	15.52	168	453	121	72	14
II	19-6-50	15-9-50	0.365	0.365	285	285	19.2	1.73	8.50	91	376	91	100	0
III	20-9-50	12-12-50	0.365	0.340	285	265	15.0	1.60	6.15	68	333	49	71	7
IV	18-12-50	14-3-51	0.340	0.348	265	271	10.8	1.84	5.09	55	326	61	100*	(0)*
V	20-3-51	16-6-51	0.348	0.310	271	242	30.6	1.31	10.23	110	852	81	74	11
VI	22-6-51	20-9-51	0.310	0.285	242	222	25.0	1.23	8.21	89	311	69	78	9
TOTAL											53.75	471		

\* Actually there was more release of K than the amount taken up by the plant and hence there was increase in exchangeable K

Results given in Table VII show that the level of exchangeable potassium fell from 0.425 to 0.365 m.e. per 100 gm. soil during the three-month period at the end of which the first crop was harvested i.e., there was a decrease of 0.060 m.e. In the next five crops taken together, the level of exchangeable potassium fell by 0.080 m.e. only. The maximum drop took place during the growth of the first crop. There was a total decrease of 110 lb. of exchangeable potassium per acre during six consecutive croppings of *bajri*. This decrease in exchangeable potassium hardly affected the yield. The lower yield in the third and fourth crops may be attributed to cold weather during the period between November to March when the crops were taken as *bajri* thrives well in hot weather only. The next two crops took up larger quantities of potassium. The total amount of potassium taken up by *bajri* plants in six successive crops after deducting potassium per cent in seeds was 581 lb. per acre, of which 110 lb. was derived from exchangeable potassium. Thus 471 lb. of potassium must have come from non-exchangeable form or 81 per cent of the total quantity of potassium taken up by six crops was derived from non-exchangeable form in 18 months. Though 471 lb. of potassium was obtained from non-exchangeable form, the level of exchangeable potassium fell from 332 to 222 lb. or to 68 per cent of the initial value. Other workers observed a much greater decrease in exchangeable potassium. Ayres [1949] found that with 7 crops of Sudan grass it was reduced to 20 per cent. Similar results were obtained by Hoagland and Martin [1933], Chandler *et al.*, [1945] and Bear *et al.*, [1944]. The reason why such a pronounced decrease in the level of exchangeable potassium did not take place in the present case can only be guessed. Though *bajri* is not a heavy consumer of potassium like clover, it is capable of taking up 581 lb. per acre of potassium in six crops. As the level of exchangeable potassium fell from 332 to 222 lb. only while *bajri* consumed 581 lb. of potassium, it is reasonable to assume that potassium is released in *goradu* soil from the nonexchangeable form at a sufficient rapid rate to maintain a fairly high level of exchangeable potassium.

When the release of non-exchangeable potassium on cropping is compared with that given by soils in moist storage during six successive leachings in a period of 18 months, it is found that *goradu* soil in moist storage liberates only 60 per cent of that extracted by plants from non-exchangeable form. The reason, suggested for this pronounced biological influence upon the rate of release of non-exchangeable potassium as compared with that of stored moist soils, is that the roots may be considered to be withdrawing potassium from the soil solution as fast as it is released. This action may produce a pronounced weathering effect upon the potash minerals. Such an action would be absent in stored soils. Tending towards more rapid release of non-exchangeable potassium in stored soils, however, is the fact that levels of exchangeable potassium are lower in the stored soils than in the cropped ones. But it is necessary to remember that values of exchangeable potassium represent average values for the soil as a whole, and that micro-levels of exchangeable potassium at points of contact between soil particles and absorbing root surfaces are presumably far below the average values. According to the "contact exchange" views of



Jenny and Overstreet [1939], it is possible to visualise the absorption of potassium by roots from weathered surfaces of potash minerals directly.

#### SUMMARY

(1) Release of nonexchangeable potassium in *goradu*, *kiari* and black cotton soils has been studied in moist condition. The soils were given a previous fixation treatment with different quantities of potassium and release of nonexchangeable potassium determined. During an 18-month period, untreated *goradu*, *kiari* and black cotton soils liberated 250 to 303, 382 to 411 and 468 to 480 lb. of nonexchangeable potassium per acre respectively. The soils, which had fixed larger quantities of potassium during previous treatments, also liberated larger quantities. The highest quantities liberated in K-treated soils were 699, 771 and 950 lb. per acre for *goradu*, *kiari* and black cotton soils respectively during an 18-month period by six successive leachings.

(2) The quantities of nonexchangeable potassium released when the soils were kept in the dry state were greater than in the moist state.

(3) The quantities of nonexchangeable potassium released in Na-, Ca-, H- and  $\text{NH}_4$ -soils were in a decreasing order.

(4) Sterilized soils liberated potassium showing that microbiological factor is not responsible for the release of nonexchangeable potassium.

(5) During six continuous croppings of *bajri* in 18 months on *goradu* soil, to which all elements necessary for plant growth except potassium were added, the exchangeable potassium taken by crops was 110 lb. and nonexchangeable 471 lb. per acre. The exchangeable potassium content decreased from 332 to 222 lb. per acre, when plants actually extracted 581 lb. of potassium. The yield of *bajri* was not affected but the percentage of potassium in the plant decreased. Thus, in spite of continuous cropping, *goradu* soil is capable of maintaining fairly high amount of exchangeable potassium and is also capable of satisfying potassium needs of crops.

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# PHYSICO-CHEMICAL PROPERTIES OF THE SURFACE SOILS OF THREE TYPES OF PADDY AREAS

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**I**N Bengal there are three types of paddy lands, viz., *aus* or autumn paddy, *aman* or winter paddy and *boro* or spring paddy, comprising more than 75 per cent of the entire cultivated land. Of these three varieties, *aman* is the most important, being about 70 per cent, *aus* about 25 per cent and *boro* about 5 per cent of the total paddy crop grown.

*Aus* is cultivated in the high lands and the soil never remains waterlogged for any period during the year. It is usually not so productive as the other two types, viz., *aman* and *boro* soils. The *aus* paddy land is often rotated with such crops as maize, *til*, *arhar* and vegetables.

The bulk of the low land is under *aman* paddy. The soil remains waterlogged often to a considerable depth during five to seven months in the year. The *aman* paddy is grown every year on the same soil. Occasionally where conditions permit, there is a second crop (usually *rabi*) such as mustard, various types of grains and beans, etc. The productivity of the *aman* soil lies between those of *aus* and *boro* paddy soil.

The *boro* paddy growing during the driest season is restricted to the immediate neighbourhood of the permanent water courses or *beels* where it is naturally easy to keep water impounded. In certain localities this paddy comprises a substantial part of the total rice grown there.

In many places, consequent on the rolling topography and changing water courses, the above three types of land occur side by side. The yield from the *boro* land is known to be generally high, while that from *aus* land is low or poor, yet very little data are available on the physico-chemical properties of these soils, which may show the inherent difference in the productivity of these lands. The aim of the present investigation was, therefore, to make a comparative study of these properties of the soils and to find out how far the fertility of these paddy lands is related to their respective properties.

## MATERIALS

Surface soil samples up to a depth of 12 in. from adjacent *aus*, *aman* and *boro* paddy lands were collected from the following localities (at present all under East Pakistan).

- (1) Olan *beel* area (Dacca)
- (2) Mirpur (Dacca)
- (3) Kurmitola (Dacca)
- (4) Bramhanbaria (Tipperah)
- (5) Nawabganj Arial *beel* (Dacca)

Soils from *aus* land were collected just after harvest in the month of October while soils from *aman* land were collected when there was a standing crop in the same month. *Boro* paddy land soils were collected in the month of October when there was no crop.

Composite representative samples were air dried, grounded in mortar with wooden pestles and passed through 2 m.m. sieve as usual.

Methods of analysis were followed from Soil Analysis by H. C. Wright [1939] and Soil and Plant Analysis by C. S. Piper [1937]. International Soda method by G. W. Robinson and Richardson, M. [1933] was followed for mechanical analysis.

Soil nitrogen was fractionated by treating with dilute hydrochloric acid, cold and hot alkali. Acid soluble nitrogen was estimated and the residual soil was treated with cold alkali. Cold alkali extract was again fractionated. Residual soil was treated with hot alkali. Hot alkali extract was fractionated by precipitation with acid. Dissoluble nitrogen is left in the residual soil after hot alkali extract [Page and Hobson, 1932, De and Pain, 1936 and Mukherjee, 1941].

Available phosphorus was determined by Truog's method [1930]. Soil was extracted with N/500  $H_2SO_4$  buffered with ammonium sulphate.

Reserve phosphorus was determined by A. E. A. [1931] method. Soil was extracted with conc. HCl (1.16 gr.) and extract collected by filtering and washing till acid-free with water and made to a definite volume. Phosphorus was determined by Truog and Meyer's method, directly in the extract by removing the interfering substances by Warren and Pugh's method [1930].

Total phosphorus was determined in the soil fused with sodium carbonate.

In all cases colour was developed by Truog and Meyer's method [1929] with their re-agents.

## RESULTS

The mechanical composition of the soils is given in Table I.

TABLE I  
*Mechanical composition of soils*

Locality	Soil type	Loss by solution per cent	Coarse sand per cent	Fine sand per cent	Silt per cent	Clay per cent
Olan beel area (Dacca)	<i>Aus</i>	1.2	1.1	27.9	21.0	41.6
	<i>Aman</i>	1.1	1.6	32.1	22.8	39.1
	<i>Boro</i>	3.1	0.4	3.3	29.8	55.5
Mirpur (Dacca)	<i>Aus</i>	1.9	2.5	34.0	21.5	38.7
	<i>Aman</i>	1.2	2.8	37.0	20.4	37.0
	<i>Boro</i>	2.6	0.5	5.6	30.7	55.0

TABLE I—*contd.*  
*Mechanical composition of soils*

Locality	Soil type	Loss by solution per cent	Coarse sand per cent	Fine sand per cent	Silt per cent	Clay per cent
Kurmitola (Dacca)	<i>Aus</i>	1.4	1.1	49.9	24.9	22.5
	<i>Aman</i>	1.6	1.3	24.7	25.7	46.5
	<i>Boro</i>	2.0	1.9	3.9	18.2	65.7
Bramhanbaria (Tippa- rah)	<i>Aus</i>	1.3	0.8	66.8	17.5	12.9
	<i>Aman</i>	2.2	0.7	18.5	40.5	37.9
	<i>Boro</i>	3.5	1.7	8.9	22.1	56.8
Nawabganj, Arial beel (Dacca)	<i>Aus</i>	1.2	1.0	57.8	26.4	11.6
	<i>Aman</i>	1.3	0.6	53.9	34.4	12.4
	<i>Boro</i>	1.4	2.7	27.0	43.8	26.5

It will be seen that the percentage of clay is always highest in the *boro* soil where the three types of soils occur adjacent to each other. The value generally follow the order *boro—aman—aus*. Fine sand follows the reverse order. Coarse sand rarely exceeds 2 per cent. These textural differences have resulted from the varying topography of the lands. *Aus* soil, situated at a higher level loses some of its finer particles with run off water and these are ultimately received by the low lying *boro* land. Silt has irregular distribution.

The base exchange capacity and exchangeable bases in the soils are given in Table II.

TABLE II

*Base exchange capacity and exchangeable bases in soil (m.e. per 100 g.)*

Locality	Soil type	Base Ex. capacity	Total Ex. base	Degree of satura- tion	Ex. Ca	Ex. K	pH
Olan beel area (Dacca)	<i>Aus</i>	10.6	7.4	69.6	3.28	0.03	5.28
	<i>Aman</i>	12.2	5.9	48.4	4.00	0.10	5.08
	<i>Boro</i>	23.9	13.0	54.4	11.71	0.43	5.28
Mirpur (Dacca)	<i>Aus</i>	9.9	9.4	94.7	6.39	0.11	6.04
	<i>Aman</i>	12.2	7.2	59.9	4.67	0.16	5.95
	<i>Boro</i>	19.9	12.9	64.8	10.39	0.32	5.37
Kurmitola (Dacca)	<i>Aus</i>	6.2	4.3	70.9	3.26	0.13	5.11
	<i>Aman</i>	16.8	8.1	48.1	5.59	0.71	4.69
	<i>Boro</i>	25.7	10.4	40.4	8.69	1.11	4.71



TABLE II—*contd.**Base exchange capacity and exchangeable bases in soils (m.e. per 100 g.)*

Locality	Soil type	Base Ex. capacity	Total Ex. bases	Degree of saturation.	Ex. Ca	Ex. K	pH
Bramhanbaria (Tipperah)	<i>Aus</i>	9.0	8.4	93.2	6.07	0.11	5.92
	<i>Aman</i>	22.6	11.9	52.7	11.45	0.26	5.94
	<i>Boro</i>	31.3	12.0	38.3	11.42	0.48	5.08
Nawabganj, Arial beel (Dacca)	<i>Aus</i>	16.3	10.1	62.3	9.16	0.03	5.03
	<i>Aman</i>	23.9	10.2	42.6	9.63	0.41	5.19
	<i>Boro</i>	29.8	13.8	46.3	11.71	0.82	4.96

As the clay fraction is highest in *boro* soil, the base exchange capacity also has the highest value in this soil. The total exchangeable bases are also high, but the degree of saturation is always low, the highest value being given by *aus* soil. This has resulted in a lower pH value for *boro* soil than for *aman* and *aus*, although all of them are distinctly acidic. Exchangeable calcium is present in sufficient amount in all the soils varying from 50 to 90 per cent of the total exchangeable bases.

The value for exchangeable potassium increases in the order *aus aman boro*, but even in *boro* soil the value is rather too low.

Percentages of organic carbon and total nitrogen in the soils are given in Table III.

TABLE III

*Organic carbon and total nitrogen in soils*

Locality	Soil type	Organic carbon (per cent)	Total nitrogen (per cent)	C/N
Olan beel area (Dacca)	<i>Aus</i>	0.86	0.11	7.6
	<i>Aman</i>	0.90	0.11	7.8
	<i>Boro</i>	4.50	0.33	13.6
Mirpur (Dacca)	<i>Aus</i>	0.69	0.09	7.5
	<i>Aman</i>	0.84	0.12	6.9
	<i>Boro</i>	2.87	0.32	8.9
Kurmitola (Dacca)	<i>Aus</i>	0.93	0.10	9.9
	<i>Aman</i>	1.80	0.15	11.4
	<i>Boro</i>	4.43	0.36	12.0
Bramhanbaria (Tipperah)	<i>Aus</i>	0.77	0.08	9.1
	<i>Aman</i>	3.43	0.37	9.0
	<i>Boro</i>	4.65	0.42	10.9
Nawabganj, Arial beel (Dacca)	<i>Aus</i>	0.72	0.07	9.1
	<i>Aman</i>	1.24	0.12	10.6
	<i>Boro</i>	3.04	0.26	10.9

Both organic carbon and total nitrogen content increase in the order *aus* - *aman* - *boro*. The high value for organic carbon in *boro* soil, amounting to over 4 per cent in many cases, is due to longer period of waterlogging, the rate of oxidation of organic matter being restricted under such conditions. The C/N ratio is also higher in the *boro* soil than in the other cases.

The ammoniacal nitrogen (Table IV) content increases generally in the order *aus*—*aman*—*boro* but the nitrate nitrogen value follows the reverse order.

TABLE IV

*Ammoniacal and nitrate nitrogen in soils (in parts per million.)*

Locality	Soil type	Ammoniacal N.	Nitrate N.
Olan beel area (Dacca)	<i>Aus</i>	36.7	12.8
	<i>Aman</i>	37.4	3.8
	<i>Boro</i>	60.3	3.3
Mirpur (Dacca)	<i>Aus</i>	20.7	12.
	<i>Aman</i>	26.3	10.1
	<i>Boro</i>	39.1	5.7
Kurmitola (Dacca)	<i>Aus</i>	18.2	12.9
	<i>Aman</i>	63.4	5.1
	<i>Boro</i>	100.9	5.1
Bramhanbaria (Tipperah)	<i>Aus</i>	9.0	20.8
	<i>Aman</i>	90.5	5.6
	<i>Boro</i>	93.1	6.1
Nawabganj, Arial beel (Dacca)	<i>Aus</i>	4.1	17.5
	<i>Aman</i>	5.8	9.7
	<i>Boro</i>	13.7	5.0

The *boro* paddy soil, as has already been stated, remains waterlogged almost throughout the year, while the *aman* paddy soil remains waterlogged for five to seven months and the *aus* paddy soil remains free all the time from waterlogging. The decomposition of added plant material and animal residue and further the humus itself may, therefore, be different for the three types of soils. These differences, if any, must bring about considerable difference in the nature of the nitrogenous compounds in the soils. In order to test this, the organic nitrogenous compounds are fractionated by the method already mentioned under the head "Methods".

Table V gives the value of nitrogen in parts per 100 gm. of soils in the different fractions.

TABLE V  
Nitrogen contents in different fractions of organic (parts per 100 gm.) soils

Locality	Soil type	N extracted by direct acid treatment	Cold alkali extract		Hot alkali extract		Alkali or acid-soluble
			Humic N	Non-humic N	Humic N	Non-humic N	
Olan beel area (Dacca)	<i>Aus</i>	0.0084	0.0064	0.0434	0.0101	0.0378	0.0224
	<i>Aman</i>	0.0056	0.0034	0.0322	0.0179	0.0490	0.0309
	<i>Boro</i>	0.0134	0.0087	0.0983	0.0255	0.0916	0.0789
Kurmitola (Dacca)	<i>Aus</i>	0.0054	0.0048	0.0294	0.0008	0.0314	0.0210
	<i>Aman</i>	0.0084	0.0123	0.0434	0.0109	0.0352	0.0456
	<i>Boro</i>	0.0207	0.0535	0.0781	0.0459	0.0619	0.0769

It will be seen that the amounts of nitrogen increase generally in all the fractions in the order *aus* -*aman* -*boro*. Only in the case of Olan beel area the acid-soluble and cold-alkali-soluble nitrogen of *aman* soil are less than the corresponding values of *aus* soil.

The values for available, reserve, and total phosphorus in parts per million of the soils are reported in Table VI.

TABLE VI  
(Available reserve and total phosphorus in soils (in parts per million))

Locality	Soil types	Available P	Reserve P	Total P
Olan beel area (Dacca)	<i>Aus</i>	1.72	23.0	65.0
	<i>Aman</i>	4.02	46.5	75.0
	<i>Boro</i>	5.91	27.0	80.0
Mirpur (Dacca)	<i>Aus</i>	3.08	40.0	110.0
	<i>Aman</i>	5.19	26.0	90.0
	<i>Boro</i>	3.80	60.0	115.0
Kurmitola (Dacca)	<i>Aus</i>	7.07	20.0	180.0
	<i>Aman</i>	4.37	40.0	85.0
	<i>Boro</i>	6.67	50.0	110.0
Bramhanbaria (Tipperah)	<i>Aus</i>	9.00	11.0	260.0
	<i>Aman</i>	2.62	11.0	120.0
	<i>Boro</i>	1.17	12.0	130.0
Nawabganj, Arial beel (Dacca)	<i>Aus</i>	18.01		
	<i>Aman</i>	16.80		
	<i>Boro</i>	12.28		

The available phosphorus content is very low in all the soils and even the total phosphorus value is not very high. The variation also is not regular.

### SUMMARY

The physico-chemical studies of the paddy soils of Bengal indicate that the *boro* soils are always richer in the clay content than the other two types of soils, viz. *aus* and *aman* soils when lying adjacent to each other. These *boro* soils are richer, in organic matter and total nitrogen content unlike other tropical soils, and have higher exchangeable bases, principal cation being the calcium. *Boro* soils have also higher base exchange capacity. This soil possesses higher inherent fertility which agrees fairly well with the general observations that the *boro* paddy has higher yield than the adjacent *aus* or *aman* for equal areas. *Aman* soil, in turn appears to be more productive than *aus* soil. It may, however, be pointed out that the *boro* soil may not prove to be very suitable for crops other than those which grow under waterlogged conditions. This is a point which deserves careful consideration when planning is made for reclamation by drainage of beel and other low lying areas of Bengal.

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# PHYSICO-CHEMICAL PROPERTIES, GROWTH AND JUICE CHARACTERS OF SUGARCANE IN RELATION TO NITROGEN SUPPLY

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(With one Text-figure)

**I**NVESTIGATIONS on sugarcane reported earlier showed outstanding variations in physico-chemical properties of leaf and stem sap in different varieties [Lal and Tandon 1954]. It was made evident that variations in sap characteristics of top and bottom canes or of stem and leaf tissues were as important as the changes recorded in the variety as a whole. How far the variations in growth induced as a result of nitrogen fertilization, are accompanied by changes in physico-chemical properties of the sugarcane sap, is elucidated in this article. Light is also thrown on the potentialities of different varieties to respond to nitrogen application. Emphasis is laid on the maximum possible yield in relation to nitrogen manuring and its relation to the changes in the various physico-chemical properties of the sugarcane sap.

## MATERIAL AND METHOD

The investigations were conducted on 16 varieties of sugarcane viz., ORB 234/1, CoS 109 Co 617, Co 313, Co 295, Co 453, Co 285, CoS 245, Co 622, Co 421, POJ 2878, Co 245, Co 317, Co 513, Co 312 and Co 370, grown on the Experimental Farm of the College during the cropping season of 1952-53. Planting under three levels of nitrogen viz., 0, 60 and 120 lb. N per acre in the form of sulphate of ammonia was done in rows 3 ft. apart. A basal nutrition of 40 lb.  $P_2O_5$  and 20 lb.  $K_2O$  was also given in the form of superphosphate and sulphate of potash respectively. The experiment, with two replications, was done on the test plot scale, each of the 96 plots being 10 in.  $\times$  9 in. in dimensions.

Samples were taken at three different stages of 130, 180 and 320 days in the life-cycle. Various growth and sap characteristics were recorded at the first two stages in the manner similar to that reported earlier [Lal and Tandon, 1954a]. At maturity, weight of component parts and juice characters were also recorded. The variations in these directions were discussed in relation to the level of nitrogen applied and the intrinsic fertility level of the soil.

## EXPERIMENTAL FINDING AND DISCUSSION

### *A. Effect of levels of nitrogen, on the growth characters and physico-chemical properties of different varieties*

Statistical analysis of the data at three stages of 130, 180 and 320 days showed certain outstanding effects. The varieties showed significant differences in the purity percentage of the juice, while in other growth characters, differences were largely

insignificant. Levels of nitrogen showed highly significant effects on weight of millable canes, sucrose and purity percentages at harvest. Age of the plant, on the contrary, showed significant effects on weight of the component parts of the shoot, but failed to indicate any marked variation in the leaf and shoot number. The outstanding effect of varieties on density, surface tension, viscosity, osmotic pressure, solute concentration, specific electrical conductivity, pH and electric potential of sap was also evident. Moisture fractions were, however, not significantly influenced by varieties. Levels of nitrogen, on the contrary, showed a highly significant effect on all sap characters excepting surface tension and osmotic pressure. Water fractions were also unaffected. Varieties  $\times$  levels interaction showed an equally significant response on all sap characters except osmotic pressure. While this was true for leaves from 130 days old crop, stem samples at 180 days also indicated significant effects on these physico-chemical properties in relation to varieties, levels of nitrogen and the interaction between the two. The specific results of these treatment combinations are given in Table I.

TABLE I

*Growth characteristics and physico-chemical properties of sugarcane varieties in relation to levels of nitrogen*

Analysis of variance

(Year 1952-53; Age 130 and 180 days)

Due to	D. F.	Mean sum of squares					
		Shoot No.	Leaf No.	Shoot Ht.	Trash Wt.	Leaf Wt.	M. Cane Wt.
Varieties (V)	15	109.480	5652.890	489.690	0.694	0.305	2.542
Levels (L)	2	72.410	5391.150	128.995	0.374	0.498	2.981
Stages (S)	1	799.260	4030.090	216492.000*	22.794*	22.176*	603.052*
V $\times$ L	30	522.620	4327.760	143.211	0.122	0.271	4.062
Error	47	57.430	3124.800	3298.800	0.119	0.233	2.914
TOTAL	95						

(Year 1952-53; Age 320 days)

Due to	D.F.	Mean sum of squares					
		M. Cane No.	M. Cane Wt.	Green		Total solids per cent	Sucrose per cent
				tops Wt.	Trash Wt.		
Varieties	15	44.979	4.518	0.290	0.082	0.864	2.428
Levels	2	33.156	27.844*	0.572	0.049	1.577	3.489*
Error	30	31.256	6.639	0.359	0.135	0.670	1.299
TOTAL	47						

\* Significant at 5 per cent level

TABLE I—*contd.**Effect of different varieties of sugarcane and levels of nitrogen on physico-chemical properties of leaf sap*

M. S. S. $\times$ 1,000													
(Analysis of variance)													
(Age=130 days : Temperature 21°C)													
Due to	D.F.	Density	Surface tension	Viscosity	Osmotic pressure	Solute concentration	Electric resistance	pH	Specific electrical conductivity	Electric potential	D.F.	Bound water	Free water
Samples	1	0.015*	0.780*	0.515*	0.2	0.003	1.3	0.930	0.003*	1289			
Varieties	15	0.060*	1.531*	1.681*	4047.0*	29.753*	2768.6*	49.955*	0.002*	159944*	15	60700	60880
Levels	2	0.035*	0.750	17.605*	1841.9	8.504*	766.0*	84.660*	0.001*	282199*	2	96332	96500
V $\times$ L	30	0.074*	2.053*	5.269*	1877.0	25.749*	2800.8*	74.865*	0.002*	263965*			
Error	47	0.003	0.114	0.114	2099.1	0.028	51.0	1.019	0.000002	3303	30	53528	54100
TOTAL	95										47		

\* Significant at 5 per cent level

TABLE I—*contd.*  
*Effect of different varieties of sugarcane and levels of nitrogen on physico-chemical properties of stem sap*

(Analysis of variance)													
(Age = 180 days ; Temperature 21°C)													
M. S. S. $\times$ 4,000													
Due to	D.F.	Density	Surface tension	Viscosity	Osmotic pressure	Solute concentration	Electric resistance	pH	Specific electrical conductivity**	Electric potential	D.F.	Bound water	Free water
Samples	1	0.035	0.047	0.612*	0.001	0.3	2448.0*	10.0	0.151	19260			
Varieties	15	0.078*	1.740	8.878*	2063.0*	410.5*	443602*	420.0*	1.138*	1457090*	15	27630	32430
Levels	2	0.121*	0.402	6.757*	2129.0*	470.4*	5900*	440.0	0.153*	1314320	2	35090	54770
V $\times$ L	30	0.001*	5.160	8.338*	2818.4*	296.7*	76215*	350.0*	1.983*	1165023*			
Error	47	0.011	13.336	0.049	10.8	0.283	358.0	150.0	0.009	15210	30	55775	56240
TOTAL	95										47		

\* Significant at 5 per cent level  
 \*\* M. S. S.  $\times$  1,000,000.

### B. *Comparative growth, yield and juice quality of varieties*

Comparative studies on the growth of 16 varieties of sugarcane showed that varieties could be classified into groups of high and low potentialities of growth (Table II). Thus Co 312 topped the list inasmuch as all the external growth characteristics like number of millable canes, leaf number and height. Weight of leaf, trash and cane also attained their maximum in this variety, but it had one serious drawback that it was poor in total solids, sucrose and purity percentages of juice. Variety Co 285 was, on the other hand, fairly high in sucrose, purity coefficient and total solids and was also superior to many varieties in some of the growth characters. Next in order was Co 317 which showed fairly good growth and juice quality.

Among varieties which showed the poorest growth, mention may be made of ORB 234/1 which indicated a very poor monsoon stand with meagre growth of leaves and tillers, and low weight of canes. Variety CoS 109 also showed poor leafy growth and low millable cane weight. It, however, showed medium quality of juice as compared to other varieties. The next poor variety was CoS 245 which again exhibited poor performance in growth and juice characters.

Analysis of the responses of high and poor yielding varieties showed at least two distinct classes :

Class I.—Varieties with desirable qualities of growth, yield and sucrose, e.g. Co 312, Co 317, Co 421 and Co 285.

Class II.—Varieties with poor qualities of growth, yield and sucrose, e.g. ORB 234/1, CoS 245, CoS 109 ; variety Co 622 although reported to be better in other parts of India, did not fare well under Banaras conditions.

Differences between these two classes of varieties in majority of cases were statistically significant. Other varieties were intermediate between these two extremes and showed occasionally the characteristics of varieties of class I and at other time exhibited features akin to varieties of class II.

### C. *Comparative physico-chemical properties of varieties*

So far as physico-chemical properties were concerned, Co 245 excelled all other varieties in viscosity and osmotic pressure of the sap at 180 days in the life-cycle. This variety also showed other desirable qualities of high density and high bound water content of stem at this period of the life-cycle. It also excelled majority of the other varieties in viscosity and osmotic pressure of the leaf sap at 130 days age. This variety also showed low electric potential of leaf sap and free water content of stem (Table III). Other varieties, which indicated desirable variations in physico-chemical properties included CoS 245, Co 313 and Co 317. Varieties with poor physico-chemical properties consisted of Co 312, Co 295 and ORB 234/1.



TABLE II

*Varietal sequence in relation to various growth characters and juice qualities*

Characters	Varieties—High to Low										S.D. at 5 per cent
	<i>Early stages of the life-cycle</i> (130 and 180 Days)										
* No. of millable canes	Co 317 29.1	Co 421 28.1	Co 312 26.5	Co 513 25.7	Co 285 25.3	Co 370 25.1	Co 295 25.6	CoS 109 23.3			8.81
	POJ 2878 20.7	Co 245 20.5	Co 313 20.3	Co 617 19.8	Co 453 19.0	CoS 245 17.0	Co 622 16.1	ORB 234/1 15.1			
* Leaf Number	Co 312 240.1	Co 513 239.8	Co 245 237.1	Co 317 232.5	Co 421 200.3	Co 370 195.1	Co 313 191.3	Co 285 190.7			64.88
	Co 295 189.0	Co 453 182.7	CoS 109 181.1	Co 617 171.5	POJ 2878 169.3	Co 622 169.0	CoS 245 160.7	ORB 2314/ 136.1			
* Wt. of green leaves (kg.).	Co 312 1.002	Co 295 1.379	Co 317 1.263	Co 370 1.263	Co 513 1.200	Co 453 1.142	Co 617 1.109	POJ 2878 1.030			0.561
	Co 313 0.997	Co 285 0.996	Co 245 0.906	Co 421 0.907	CoS 245 0.902	ORB 234/1 0.861	CoS 109 0.787	Co 622 0.737			
* Wt. of canes (kg.)	Co 312 5.39	Co 317 4.67	Co 295 4.48	Co 617 4.04	Co 453 4.01	Co 370 3.95	Co 421 3.70	POJ 2878 3.69			1.984
	Co 285 3.56	Co 313 3.55	CoS 245 3.45	Co 245 3.27	Co 622 3.17	Co 513 3.06	ORB 234/1 3.02	CoS 109 2.99			
* Wt. of trash	Co 312 0.898	Co 295 0.692	Co 317 0.683	Co 370 0.663	Co 617 0.639	Co 313 0.628	Co 285 0.599	CoS 245 0.591			0.401
	POJ 2878 0.537	Co 421 0.585	Co 453 0.578	ORB 234/1 0.522	Co 622 0.509	Co 245 0.500	CoS 109 0.473	Co 513 0.453			
	<i>Juice qualities at harvest</i> (320 Days)										
Total solids per cent	Co 421 23.0	Co 285 22.6	Co 317 22.5	CoS 109 22.4	Co 295 22.3	Co 617 22.3	POJ 2878 22.2	Co 370 22.2			1.36
	Co 245 22.0	Co 513 22.0	Co 453 21.9	ORB 235/1 21.9	Co 622 21.8	Co 312 21.4	CoS 245 21.2	Co 313 20.9			

\* Per 5 in. row

*Growth characters per 5 in. row at harvest*  
(320 Days)

Sucrose per cent	Co 285		Co 317		Co 421		POJ 2878		Co 513		Co 245		Co 622	
	20-45	19-20	20-11	18-93	20-07	18-86	19-76	18-82	19-70	19-66	19-43	17-15	19-32	17-15
Purity per cent	Co 286		Co 513		Co 317		POJ 2878		Co 622		Co 245		Co 421	
	90-22	88-65	88-65	88-65	89-03	88-99	88-99	88-99	88-99	88-99	88-99	88-99	88-99	88-99
No. of millable canes	Co 313		Co 312		Co 285		Co 513		Co 453		Co 370		Co 245	
	23-3	15-0	23-0	14-3	20-6	14-3	20-0	14-0	18-6	17-0	16-3	15-6	15-6	15-6
Ht. of tallest shoot (cm.)	Co 317		Co 295		ORB 234/1		Co 622		Co 617		Co 421		Co 8109	
	287-7	245-1	282-5	253-1	262-5	251-6	259-8	244-7	259-0	244-3	243-8	231-1	231-1	231-1
Wt. of green tops (kg.)	Co 285		Co 245		Co 312		Co 513		Co 453		Co 317		Co 313	
	2-26	1-74	2-21	1-73	2-08	1-72	1-98	1-53	1-90	1-85	1-81	1-76	1-76	1-76
Wt. of trash (kg.)	Co 370		Co 622		Co 295		POJ 2878		Co 8109		Co 617		Co 245	
	0-84	0-84	0-93	0-81	0-83	0-79	0-90	0-89	0-89	0-88	0-88	0-88	0-88	0-88
Wt. of canes (kg.)	Co 285		Co 312		Co 312		Co 317		Co 513		Co 245		Co 622	
	9-40	6-51	8-55	6-32	8-49	6-30	7-66	5-97	7-66	7-40	7-25	7-24	7-24	7-24
Wt. of canes (kg.)	Co 370		Co 313		Co 421		Co 622		Co 8109		Co 617		Co 245	
	6-51	6-51	6-32	6-32	6-30	6-30	5-97	5-97	5-81	5-71	5-30	5-30	5-30	5-30

TABLE III

*Varietal sequence in relation to various physico-chemical properties of tissue sap*

Characters	Varieties—High to Low												S.D. at 5 per cent
	Leaf Sap (130 Days)												
Density	Co 622	Co 421	Co 317	POJ 2878	Co 245	Co 453	Co 313	CoS 109					0.0100
	1-0090	1-0066	1-0045	1-0041	1-0035	1-0033	1-0031	1-0026					
	CoS 245	ORB 234/1	Co 617	Co 285	Co 513	Co 312	Co 370	Co 295					
	1-0025	1-0020	1-0019	1-0018	1-0002	0-9998	0-9980	0-9956					
Surface tension	Co 295	Co 317	Co 295	Co 453	POJ 2878	ORB 234/1	Co 245	Co 421					0.00388
	0-8201	0-8180	0-8150	0-8090	0-8090	0-8055	0-8041	0-8041					
	CoS 245	Co 617	Co 622	CoS 109	Co 317	Co 313	Co 312	Co 370					
	0-7970	0-7900	0-7870	0-7861	0-7855	0-7790	0-7760	0-7670					
Viscosity	Co 313	Co 245	ORB 234/1	Co 317	Co 617	Co 513	POJ 2878	CoS 245					0.016
	1-170	1-151	1-150	1-140	1-134	1-130	1-122	1-120					
	CoS 109	Co 622	Co 295	Co 421	Co 370	Co 453	Co 312	Co 285					
	1-120	1-117	1-115	1-111	1-107	1-107	1-090	1-080					
Osmotic pressure	Co 421	Co 317	Co 245	Co 622	POJ 2878	Co 313	CoS 109	Co 453					2.062
	8-700	8-602	8-130	8-016	7-950	7-420	7-320	7-280					
	Co 513	CoS 245	Co 285	Co 312	Co 617	ORB 234/1	Co 295	Co 370					
	7-114	7-050	7-050	6-703	6-300	6-360	6-280	6-090					
Solute concentration	Co 317	Co 421	Co 622	POJ 2878	Co 313	Co 453	CoS 245	Co 245					0.008
	0-810	0-809	0-797	0-776	0-764	0-747	0-723	0-719					
	Co 295	CoS 109	Co 513	Co 285	Co 617	Co 370	Co 312	ORB 234/1					
	0-705	0-701	0-676	0-662	0-635	0-624	0-617	0-596					

Electrical resistance	ORB 234/1	CoS 109	Co 813	Co 617	Co 285	Co 370	Co 812	Co 295	0-323
	12-45	12-38	12-13	12-01	11-75	11-65	11-46	11-23	
Sp. electrical conductivity	Co 453	Co 421	Co 245	Co 513	POJ 2878	CoS 245	Co 622	Co 317	0-00008
	11-20	11-18	11-16	11-10	10-93	10-52	10-83	10-13	
$pH$	Co 317	Co 622	CoS 245	Co 295	POJ 2878	Co 245	Co 513	Co 421	0-00008
	0-0117	0-0115	0-0113	0-0109	0-0109	0-0107	0-0107	0-0106	
$pH$	Co 453	Co 812	Co 370	Co 285	Co 313	Co 617	CoS 109	ORB 234/1	0-049
	0-0106	0-0104	0-0102	0-0102	0-0100	0-0099	0-0097	0-0094	
Electric potential	Co 453	Co 313	Co 295	Co 617	Co 421	Co 285	ORB 234/1	Co 622	2-589
	5-84	5-80	5-79	5-78	5-71	5-70	5-70	5-70	
Moisture per cent	Co 370	Co 245	CoS 109	Co 317	Co 513	CoS 245	Co 312	POJ 2878	4-055
	5-67	5-64	5-63	5-61	5-60	5-60	5-57	5-56	
Bound water	Co 312	POJ 2878	CoS 245	Co 317	Co 513	CoS 109	Co 245	Co 370	12-204
	132-0	131-0	130-3	130-1	129-8	128-1	127-3	125-3	
Free water	ORB 234/1	Co 622	Co 285	Co 421	Co 617	Co 295	Co 313	Co 453	12-23
	124-6	123-8	122-6	120-8	120-5	119-3	118-3	115-3	
Moisture per cent	Co 295	Co 453	Co 313	Co 370	Co 617	CoS 245	POJ 2878	Co 622	4-055
	70-80	69-70	69-36	69-10	69-03	68-73	68-56	68-50	
Bound water	CoS 109	Co 513	Co 285	ORB 234/1	Co 317	Co 312	Co 421	Co 254	12-204
	68-13	68-06	68-00	68-00	67-76	67-73	67-63	66-40	
Free water	Co 622	Co 421	CoS 245	Co 285	ORB 234/1	POJ 2878	Co 617	CoS 109	12-23
	31-5	30-1	29-3	24-4	23-6	22-5	22-4	21-2	
Free water	Co 295	Co 245	Co 317	Co 453	Co 313	Co 513	Co 312	Co 370	12-23
	20-7	19-9	19-9	19-5	19-3	17-8	16-2	15-3	
Free water	Co 370	Co 312	Co 513	Co 313	Co 453	Co 817	Co 245	Co 295	12-23
	84-66	83-76	82-16	80-70	80-46	80-13	80-08	79-83	
Free water	CoS 109	Co 617	POJ 2878	ORB 234/1	Co 285	CoS 245	Co 421	Co 622	12-23
	78-80	77-63	77-53	76-36	75-63	73-73	69-86	68-46	

TABLE III—*contd.*  
*Varietal sequence in relation to various physico-chemical properties of tissue sap—contd.*

Character	Varieties—High to Low										S.D. at 5 per cent
	<i>Stem Sap</i> (180 Days)										
Density	CoS 245	Co 245	Co 312	Co 622	POJ 2878	Co 421	Co 617	Co 313			
	1-043	1-041	1-039	1-039	1-038	1-038	1-038	1-037			
	Co 370	Co 285	ORB 234/1	Co 513	Co 317	Co 295	CoS 109	Co 458			
	1-037	1-036	1-036	1-035	1-034	1-033	1-031	1-028			0-0038
Surface tension	Co 617	Co 295	Co 255	Co 421	CoS 245	Co 370	ORB 234/1	Co 245			
	0-959	0-954	0-949	0-942	0-935	0-931	0-923	0-926			
	Co 313	Co 817	CoS 109	Co 453	Co 513	Co 312	POJ 2878	Co 622			
	0-928	0-920	0-919	0-911	0-908	0-907	0-900	0-923			0-134
Viscosity	Co 245	Co 617	Co 312	Co 370	CoS 109	Co 453	Co 622	POJ 2878			
	1-319	1-259	1-247	1-247	1-240	1-230	1-228	1-222			
	Co 295	ORB 234/1	CoS 245	Co 313	Co 317	Co 421	Co 513	Co 285			
	1-221	1-221	1-210	1-208	1-195	1-195	1-186	1-170			0-081
Osmotic pressure	Co 245	Co 312	CoS 245	Co 622	POJ 2878	Co 421	ORB 234/1	Co 617			
	12-693	12-212	11-954	11-873	11-696	11-463	11-273	11-197			
	Co 313	Co 453	Co 370	Co 513	Co 295	Co 317	Co 295	CoS 109			
	11-196	11-071	10-999	10-857	10-807	10-804	10-761	10-716			0-121
Solute concentration	Co 312	ORB 234/1	CoS 109	Co 313	Co 453	Co 370	Co 421	Co 622			
	2-507	2-164	1-967	1-931	1-921	1-894	1-877	1-875			
	Co 245	Co 295	Co 617	POJ 2878	CoS 245	Co 513	Co 235	Co 317			
	1-843	1-708	1-665	1-665	1-662	1-603	1-576	1-363			0-019



Electrical resistance	Co 133	Co 453	Co 245	Co 213	Co 370	CoS 109	Co 617	Co 513
	46.3	45.2	49.9	40.5	40.0	39.3	37.7	39.0
Sp. electrical conductivity	CoS 245	Co 317	POJ 2878	Co 622	ORB 234/1	Co 421	Co 285	Co 295
	35.8	35.6	35.4	35.2	35.2	34.2	32.3	28.9
pH	Co 295	CoS 245	Co 255	Co 317	Co 513	POJ 2878	Co 421	Co 622
	0.0046	0.0038	0.0037	0.0036	0.0035	0.0035	0.0035	0.0035
Electric potential	CoS 109	ORB 234/1	Co 617	Co 245	Co 370	Co 312	Co 453	Co 313
	0.0034	0.0034	0.0033	0.0032	0.0032	0.0028	0.0028	0.0027
Moisture per cent	Co 312	CoS 245	ORB 234/1	Co 313	Co 513	Co 295	Co 370	Co 622
	5.176	5.600	5.516	5.500	5.483	5.483	5.450	5.416
Bound water	Co 317	CoS 109	Co 617	Co 245	Co 421	Co 285	POJ 2878	Co 453
	5.400	5.366	5.336	5.066	5.000	4.950	4.716	5.146
Free water	POJ 2878	Co 421	Co 285	Co 245	Co 617	Co 622	CoS 109	Co 453
	138.17	108.17	167.67	160.00	143.83	142.83	142.83	141.00
	Co 317	Co 370	Co 313	Co 295	Co 513	ORB 234/1	CoS 245	Co 312
	140.50	138.83	137.17	135.67	135.50	133.50	133.17	124.50
	Co 313	ORB 234/1	Co 370	Co 421	Co 312	Co 622	Co 513	Co 617
	82.9	81.0	79.0	78.0	77.3	77.6	76.9	76.6
	Co 245	Co 285	Co 453	POJ 2878	CoS 109	CoS 245	Co 317	Co 295
	76.6	76.1	76.1	76.0	75.9	75.1	74.5	74.0
	Co 421	Co 312	Co 245	POJ 2878	Co 453	Co 370	ORB 234/1	CoS 245
	26.6	25.4	25.1	23.3	23.2	23.2	22.2	22.0
	Co 622	Co 313	Co 513	CoS 109	Co 617	Co 317	Co 285	Co 295
	21.8	20.8	20.0	19.0	17.7	17.6	16.1	15.9
	Co 295	Co 285	Co 317	Co 617	CoS 109	Co 513	Co 313	Co 622
	84.1	83.9	82.4	81.0	80.0	79.2	78.2	78.2
	CoS 245	ORB 234/1	Co 370	Co 453	POJ 2878	Co 245	Co 312	Co 421
	78.0	77.3	76.8	76.3	76.7	74.9	74.6	73.4

Considering all these facts Co 245, Co 313, CoS 245 and Co 317 appeared to be relatively better varieties as judged on the basis of their physico-chemical properties. Of all these, Co 317 appeared to possess common characters of fairly good growth, yield and sucrose content alongside high electrical conductivity of leaf and stem, high solute concentration, osmotic pressure and density of the leaf sap. How far good growth performances were related to these physico-chemical properties was difficult to be assessed at this stage. The relation between good growth and better juice quality and the higher values of various physico-chemical properties in variety Co 317 point out some such obvious relation. Again, poorest growth performance of ORB 234/1 was also found to be associated with poor solute concentration, specific electrical conductivity and electric potential of the stem sap. It therefore, appeared that such physico-chemical properties as electrical conductivity, solute concentration and osmotic pressure of the leaf sap might show a marked correlation with the good growth performances, high yield and better quality of varieties.

#### *D. Manurial effect on growth and physico-chemical properties*

Application of nitrogen, in general, was found to improve growth in several directions. Thus number of millable canes, weight of green tops and trash, yield of millable canes and purity percentages of the cane juice were relatively higher under 120 lb. nitrogen (Table IV). A 60 lb. of N dose also appeared favourable from the viewpoint of sucrose content at maturity. It was also evident that a 120 lb. N dose produced a larger number of leaves and shoots than other levels during the monsoon period. Thus favourable variation in growth, yield and juice quality under 120 lb. N was also related to high density, surface tension, viscosity and electrical potential of leaf sap. This dose also improved the bound water content markedly in both the leaf and stem tissues.

In analysing the response of various nitrogenous fertilizers, use might, therefore, be made of such measurements as density, surface tension, viscosity and electric potential of the leaf sap and bound water content of leaf and stem tissues. High intensity of these physico-chemical properties induced as a result of high nitrogen fertilization were related to better growth, yield and sucrose content of sugarcane. The extent of correlation exhibited between the sap characteristics and growth performance, however, needs careful scrutiny and investigations under more elaborate field conditions.

TABLE IV

*Manurial effect on growth and physico-chemical properties of sugarcane**(Growth and juice characters)*

Character	N levels (in lb. per acre)			S. D. at 5 per cent	N levels (in lb. per acre)			S. D. at 5 per cent
	0	60	120		0	60	120	
	<i>At 130 and 180 days</i>				<i>At harvest</i>			
*No. of Millable canes	22-594	20-563	23-500	3-81	14-9	16-2	17-8	4-03
*Leaf No.	199-97	177-94	200-84	28-09	255-18	253-30	251-17	28-91
*Leaf Wt. (kg.)	1-196	0-947	1-083	0-2431	1-55	1-74	1-93	0-431
*Trash Wt. (kg.)	0-633	0-478	0-637	0-1735	0-72	0-82	0-82	0-264
*Cane Wt. (kg.)	3-968	3-413	3-910	0-859	5-81	6-66	8-39	1-859
Sucrose per cent					19-46	19-59	18-27	0-823
Total solids per cent					22-20	22-20	21-70	0-590
Purity per cent					87-37	88-22	84-00	1-649

*(Physico-chemical properties)*

	<i>Leaf sap 130 days</i>				<i>Stem sap 180 days</i>			
Density	1-0027	1-0012	1-0032	0-0043	1-038	1-034	1-036	0-0017
Surface tension	0-800	0-797	0-795	0-0005	0-930	0-923	0-929	0-0581
Viscosity	1-130	1-097	1-140	0-0054	1-239	1-216	1-225	0-0035
Osmotic pressure	7-520	7-041	7-257	0-7541	11-640	11-150	11-255	0-0523
Solute concentration	0-718	0-720	0-691	0-0027	1-944	1-802	1-703	0-0084
Electrical resistance	11-203	11-512	11-331	0-1140	37-81	36-96	37-52	0-301
Sp. E. conductivity	0-0170	0-0104	0-0108	0-00002	0-0032	0-0035	0-0034	0-00004
pH	5-73	5-68	5-63	0-016	5-21	5-44	5-38	0-194
Electric potential	122-0	125-1	142-9	0-915	152-59	140-56	142-75	1-963
Bound water	20-34	20-66	27-44	5-285	19-74	22-20	22-40	5-400
Free water	78-40	79-34	75-25	5-290	80-89	77-77	77-61	5-410

\* Per 5 in. row.

E. *Observed yield under different doses and basic nitrogen level in soil*

Out of 16 varieties used for these investigations Co 421, Co 317 and Co 312 which were found to possess good and desirable qualities of yield and sucrose, were tested for maximum potentialities of yield by the Mitscherlich's technique as follows:

The growth data were utilized for the determination of (a) maximum possible yield as a result of these treatments, and (b) the basic level of nutrient in the medium of growth. For the determination of these important characteristics use was made of the following formulae:

$$A = \frac{K_y - Y_0}{K - 1}$$

where,  $K = \text{antilog } c \times x$ , and  $c$  and  $x$  were the constant for the fertilizer and the dose of the nutrient in gm. per plot;

$Y$  = was the yield obtained under  $x$  dose of the nutrient;

$Y_0$  = was the yield recorded for the control;

$A$  = maximum yield in mds. per acre.

$$\text{and } b = \frac{\text{Log } A - \text{Log } (A - Y_0)}{c}$$

where,

$A$  = was the maximum possible yield;

$Y_0$  = was the yield under the control;

$c$  = was the fertilizer constant. The value of this constant —  $c$  — was taken as 0.122 for nitrogen [Wilcox, 1928];

$b$  = basic level of nutrient in maunds per acre.

Based on the values of  $A$  and  $b$  the expected yields of sugarcane varieties were also calculated by the formula :

$$\text{Log } (A - Y) = \text{Log } A - c(b + x)$$

The extent to which these expected values calculated after the above equation, tallied with the recorded yield of sugarcane under different levels of N was also computed. Maximum yield in variety Co 421 was found to be fairly high of the order of 1368 maunds per acre. Next in order of efficiency was the variety Co 312 which gave a maximum possible yield of 835 maunds per acre. Co 317, on the other hand, gave a maximum possible yield of 598 maunds per acre only. A critical examination of the potentialities of the nitrogen in improving the yield of the varieties and the respective yield recorded under field conditions showed that without any added nitrogen to the soil, the observed yields were only 21.7, 23.4 and 10.8 per cent of the theoretical maximum recorded for Co 421, Co 317 and Co 312 respectively. At 60 lb. N level slight improvement in yield was recorded, reaching 40.6, 39.1 and 27.6 per cent of the maximum. It was significant to note that at the highest level of 120 lb. N per acre the observed yields

were only 45-47.3 per cent of the maximum in these varieties. It would appear from Table V that there was very little difference in the three varieties so far as the percentage of the maximum yield under different nitrogen levels were concerned. Theoretically this maximum yield would be attained when the dose of the nitrogen reached the level of 24 maunds nitrogen per acre. This theoretical dose was hardly a practical proposition. If the criterion of yield was taken as 50 per cent of the theoretical maximum, data obtained (Fig. I) indicated that a dose of three maunds of nitrogen per acre was the required quantity for attaining this limit in different varieties. The requirement of three maunds of nitrogen per acre appeared to be a feasible proposition. Since all the three varieties differing characteristically in their growth and physico-chemical properties required the same amount for the target of 50 per cent of their yield, the suggestion was made that other varieties might as well exhibit similar response regarding their nitrogen requirement.

TABLE V

*Observed and expected yield under different doses, basic N. level in soil and maximum possible yield in sugarcane varieties calculated after Mitscherlich's formula*

Varieties	N. Dose (lb. per acre)	Yield observed (mds. per acre)	Maximum possible yield (mds.) (A)	Basic N. level in soil (mds.) (b)	Yield as per cent of A
Co 421	0	298	1368	1.22	{ 21.7 40.6 45.8
	60	556			
	120	627			
Co 317	0	140	598	0.95	{ 23.4 39.1 47.3
	60	234			
	120	283			
Co 312	0	91	835	0.41	{ 10.8 27.6 45.6
	60	231			
	120	376			
			Mean	0.86	

If the requirement of nitrogen was taken as three maunds per acre for achieving the 50 per cent of the maximum yield, and if the average basic level of the effective nitrogen in the soil (b) was 0.86 maunds per acre, as noted under the present instance, the maximum quantity of added nitrogen should be at the limit of two maunds per acre for achieving this target figure.



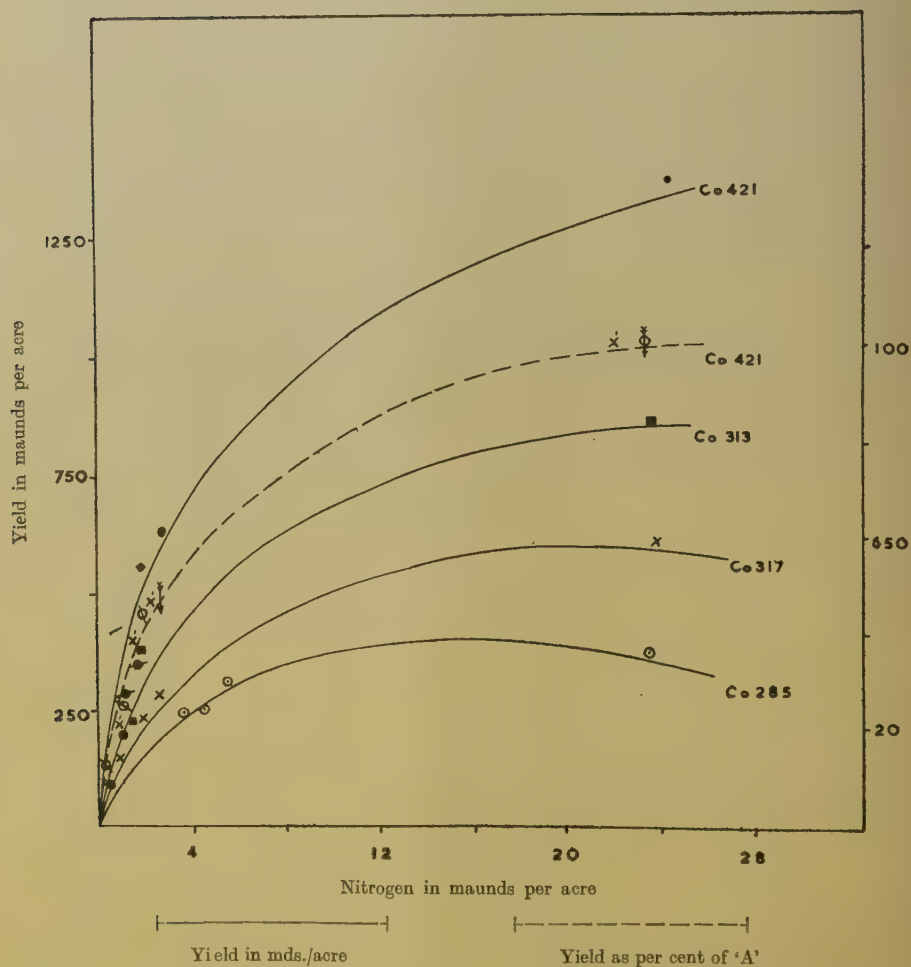


FIG. 1. Observed yield under different doses, maximum possible yield and basic nitrogen level

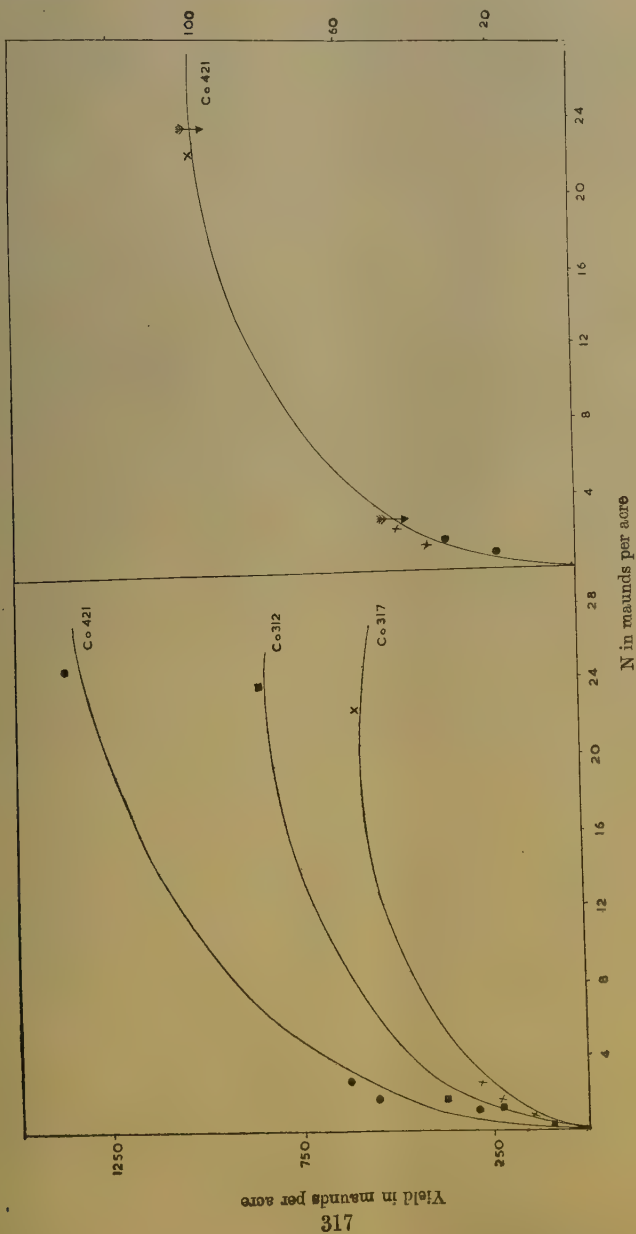


Fig. 1—*contd.*—Observed yield under different doses, maximum possible yield and basic nitrogen level

## SUMMARY

In the previous pages comparative growth of the 16 varieties of sugarcane under three levels of 0, 60 and 120 lb. nitrogen was investigated under field conditions.

Varieties could be classified into two classes :

Class I.—Varieties with desirable qualities of growth, yield and sucrose, e.g., Co 312, Co 317 and Co 421.

Class II.—Varieties with undesirable qualities of poor growth, yield and sucrose, e.g., ORB 234/1, CoS 245 and CoS 109.

Differences between varieties of these two classes were statistically significant. Other varieties did not exhibit significant variations.

Co 312 showed high electric potential of the leaf sap and high pH, osmotic pressure and density of the stem sap ; bound water content of the stem tissue was also high.

Co 421 showed high osmotic pressure, solute concentration and density of leaf and greater bound water in the leaf and stem tissues.

A 120 lb. dose of nitrogen was found best for majority of growth and juice characters. Better growth and juice quality under this dose were found associated with high density, surface tension, viscosity and electric potential of the leaf sap and greater bound water content of leaf and stem tissues.

Variety Co 421 showed higher potentialities of yield when supplied with nitrogen followed by variety Co 312 and Co 317. If for example 50 per cent of this maximum potentiality for yield was the target, a dose of three maunds of nitrogen per acre appeared to serve the end.

Basic level of nitrogen in the soil was found to be of the order of 0.41-1.22 with an average of 0.85 maunds per acre. Additional quantity of 2 maunds per acre was thus theoretically capable of satisfying the total requirement of nitrogen for securing 50 per cent of the maximum yield. Indications were obvious that varieties showed no difference in their nitrogen requirement.

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## DEVELOPMENT OF OIL IN THE RIPENING COCONUT

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THE observations of Pfeffer [1872] that paeony seeds detached from the plant at an immature stage when they contained no fat, developed a certain amount of fat on being kept, and of de Luca [1878] that olives could make fat after they were separated from the tree established that reserve fats stored in seeds can be developed *in situ* and need not be translocated from leaf or stem. Studies by Godlewski [1882], Gerber [1897] and Burr and Miller [1938] on the respiratory quotients of various ripening seeds like castor beans, poppy and olives indicated that most of the seed-fat is synthesised within the fruit itself. This conclusion is supported by the fact that specific fatty acids are frequently found in the endosperms of seeds which are not present in fats from other parts of the plant. Shorland [1945] found that leaf-fat from the rape plant (*Brassica napus*) did not contain any acids higher than  $C_{18}$  whereas rape oils generally contain above about 40 per cent of the  $C_{22}$  unsaturated acid, erucic acid [Sudborough, *et al.*, 1926]. The fruit-coat fat of *Stillingia sebifera* [Hilditch and Priestmann, 1930] does not contain any linoleic and linolenic acids to more than 75 per cent [Jamieson and McKinney, 1938]; similarly plum oil does not contain any linoleic or linolenic acids whereas the seed-fat contains acids lower than  $C_{14}$  [Armstrong and Allan, 1924] whereas the kernel oil contains above 60 per cent of saturated acids lower than  $C_{14}$  [Armstrong, Allan and Moore, 1925].

Studies on the development of fat in a large number of oilseeds have already been reported in the literature. du Sablon [1896] reported on the development of oil in almonds and walnuts; Valee [1903] on almonds; Ivanow [1912] on linseed, rape, hemp and poppy seeds; Eyre and Fisher [1915] and Eyre [1931] on linseed; Barker [1932] on linseed; Caskey and Gallup [1931] and Lonzingier and Raskina [1931] on cottonseed; Sahasrabudhe [1932] on niger seed; Humphries [1943] on cocoa; Rewald and Riede [1933] on soybean; Neumann [1941] on white lupin and Bauer [1934] on sunflower seeds. The data recorded by the above workers refer to one or more of the following details:

- (1) Percentage of fat on dry weight of seed during different stages of growth
- (2) Iodine value of fat in different stages of growth
- (3) Acid value of fat during different stages of growth

Regarding the variation in acid values, Ivanow [1912] first noticed that in rape, hemp, poppy and flax seeds considerable amounts of free fatty acids are present in the early stages of ripening (this initially high acid value gradually comes down to below about 1 per cent by the time the ripening has reached about halfway) in the above four cases in about 25-30 days after flowering. This variation in acid value is generally considered to be a general feature in the ripening of all seeds.

Regarding the variation of proportion of fat on dry weight of seed two types of variations have been evident. If we assume that fat synthesis starts in earnest only after a basic 2-3 per cent fat content is reached, then in some seeds increase in percentage fat on dry basis continues throughout the maturing of seeds as for example in almonds, walnuts, and cocoa bean (*loc. cit.*). In a second group of seeds the percentage oil content on dry weight reaches its maximum by about the middle of the period of maturing : about 20-25 days after flowering for linseed ; 50 days for cottonseed, about 45 days after flowering for niger seed ; subsequently no further changes take place in the percentage of oil on dry weight of seed, though there may be other changes and the seed may increase considerably in dry weight after this period.

The above studies also disclose variations in the iodine value of fat during development of several seeds. Ivanow [1912] found that rape, hemp and poppy seed contained oils of about the same iodine value throughout the period of maturing but in the case of linseed, Ivanow [1912], Eyre [1931] and Barker [1932] found that the iodine value of the oil remains about 120-130 for about the first 25 days after flowering : by the end of this period the maximum oil content on dry weight of seed is reached : the seed, however, requires another 5-6 weeks for maturing and during this period the iodine value changes from about 130 to about 180. A similar increase in iodine value of the oil was noticed in the case of the ripening nigerseed, cottonseed, soybean and white lupin seeds as well (*loc. cit.*). In the case of sunflower seeds Bauer [1934] observed that the iodine value remained constant at 143-144 throughout the period of maturing but variations in thiocyanogen values indicated a rise in oleic acid and fall in linoleic acid and saturated acids during ripening.

The following critical observations may be made about the foregoing studies :

(1) They are limited entirely to dicotyledonous plants ; not even a single monocot seed has been investigated in this connection so far.

(2) All the examined seeds developed the frequently occurring category of seed fats in which the major component acids were oleic, linoleic, palmitic, with occasionally stearic also as major component. In the case of rapeseed examined by Ivanow [1912] detailed study of component acid compositions has not been undertaken. No studies have been reported on fats which contain lauric, myristic or petroselinic acid as major component.

(3) The variations in the rate of synthesis of fat as well as variations in the constants of the fat have not been studied with reference to the total synthesis of fat in



the seed. For example, in the case of linseed oil it would have been extremely informative had it been evident at what percentage synthesis of total fat, the increase in iodine value or the rapid decrease in acid value starts.

Apart from the fact that the Palmae belong to the monocots, no member of which has been studied with respect to development of oil in the maturing seeds, the development of oil in the maturing coconut has another interesting aspect. In general in most other plants most of the maturing seeds on any one plant will be approximately at about the same stage of ripening while in the palmae any tree bears at the same time nuts in all stages of maturity at certain fixed intervals; further the trees bear these nuts at different stages of growth throughout the year.

A large number of details about the development of coconut are already known and the following is a short summary of the details relevant to the present work taken from the Dictionary, "*The Wealth of India*" (1950):

"The coconut is a tall and stately palm growing to a height of 80 ft. or more when fully mature, bearing a crown of large pinnate leaves. The leaves may be from 6-18 ft. long and are pinnatisect; leaflets are 2—3 ft. long, narrow and tapering. In the axil of each leaf is a spathe enclosing a spadix, 4-6 feet long, stout, straw or orange coloured and simply branched. The palm is monoecious. The female flowers are relatively few, 1 in. long and globose, borne at the base of the panicle. The male flowers are numerous, small and sweet-scented, borne towards the top of the panicle. The fruit is ovoid three-angled, 6-12 in. long, containing a single seed. The exocarp or outer husk is thick and fibrous and encloses a hard and bony endocarp (shell). Adhering inside the endocarp is the testa with a thick albuminous endosperm (meat). At one end of the shell are three pores below one of which embedded in the meat is the small embryo. The cavity of the endosperm is large and is filled in the unripe fruit with a watery fluid (coconut water); it is only partly filled in the ripe fruit.

"The coconut palm produces new flowering branches at approximately monthly intervals. From the emergence of the spadix to complete maturity of the drupe 12-13 months are normally necessary. At any one time the palm thus carries 12-13 flowering branches in varying stages of development.

"Coconut water plays an important part in the ripening of the nut and in germination. In the early stages of ripening, when endosperm formation is taking place, invert sugar and amino acids accumulate in the coconut water. The concentration of invert sugars increases as the nut ripens reaching a maximum in the 5th or 6th month. Sucrose appears thereafter and the concentration of total sugars falls. The total solids (Ca. 2.5 gm./100 cc. in the early stages) increases gradually as the nut ripens, reaching a maximum at about the 7th month, just before the kernel begins to form and then declines. Just before disappearance before germination, the water contains 2.0 gm. of total solids per 100 cc.

"Analysis of coconut water gave the following values: water 95.5 per cent; protein 0.1 per cent; fat <0.1 per cent; mineral water 0.4 per cent; carbohydrates 4.0 per cent. Sugars form an important constituent of the nut water. At the stage at which it is consumed as a beverage, the concentration of sugars is at its maximum and a large nut may contain in solution over an ounce of sugars."

It is evident from the above that the coconut takes on an average 13 months to mature and the kernel formation starts about the beginning of the 7th month after emergence of spadix when the concentration of sugars in coconut water reaches a maximum. Previous to this time there is no kernel at all in the nut and as there is no oil in the coconut water we may consider that the fat synthesis starts in the beginning of the 7th month and ends at the end of about 12 months. Each coconut tree will hence bear 7 or 8 bunches of coconuts in which varying proportions of kernel have been synthesised. Further the reddish testa, which assumes a brownish tint when mature, is laid down before the formation of kernel and it appears that there is a proportionately greater development of testa during the earlier stages, than the kernel.

For the present investigation, nuts were collected from the eight later bunches of a well nourished coconut tree; the youngest bunch represented about the 6th month and did not show any sign of formation of white kernel and hence was not further studied. From 7th month onwards the nuts showed development of kernel. The shells of all the coconuts from different bunches were of about the same size so that the amount of kernel which would ultimately be synthesised in each nut would be approximately the same and would be represented by the kernel found in the last (i.e. mature bunch) on the tree. The dry weight of kernel in the 7th month was very low and came to 188.2 gm. on an average in the mature nut. In the present article the course of development of kernel and oil in the coconut has been comparatively studied on the basis of the average amount of kernel and oil found in the mature nut on the same tree.

#### *Development of kernel in the coconut*

The development of the kernel in the ripening coconut has been studied from two viewpoints: one from the average volume of kernel and the other from the dry weight of the total kernel.

If the end of the nut containing the embedded germ may be termed as the top and the opposite end the bottom of the nut, then the kernel first starts forming on the bottommost portions of the nut and gradually starts up towards the top. In the initial stages of growth the thickness of the kernel is highest at the bottom end and gradually becomes smaller towards the top. As growth proceeds, this difference in the thickness vanishes and by the beginning of the 9th month after emergence of spadix the kernel assumes a uniform thickness throughout; at this stage the actual thickness comes to about 1.02 cm. against the 1.52 cm. found in the mature nut, i.e. about 66 per cent. Thereafter thickness of the complete kernel increases slowly and there are no further difference of thickness at top and bottom.

The dry weight of kernel is not directly proportionate to thickness of the fresh kernel at any stage. An idea of the relative dry weight per unit volume of the fresh kernel at different stages of growth as compared to the dry weight per unit volume of fresh kernel at maturity on a per cent basis, is obtained from the function  $\frac{w_1}{w_2} \times \frac{t_2}{t_1} \times 100$ , where  $W_1$  and  $W_2$  are the dry weight, of the immature and mature kernels, and  $t_1$  and  $t_2$  the mean thickness of the fresh immature and mature kernels respectively. The data relating to the development of kernel is given in Table I. It is seen from this that throughout the entire period of ripening there is a steady increase in the dry weight per unit volume of the fresh kernels.

TABLE I  
*Development of kernel in growing coconut*

Serial No.	Period after flowering (beginning of month)	Growth stage	Thickness of kernel, (cm.)			Dry weight total kernel (gm.)	Percentage development of kernel	Per cent relative dry weight per unit volume of fresh kernel on mature kernel
			Top	Bottom	Average			
1	7th	1	Trace	0.38	0.19	1.3	0.7	5.6
2	8th	2	0.38	0.76	0.57	17.8	9.5	25.3
3	9th	3	1.02	1.02	1.02	63.5	33.8	50.4
4	10th	4	1.27	1.27	1.27	94.0	50.0	59.8
5	11th	5	1.40	1.42	1.41	123.2	65.5	70.5
6	12th	6	1.52	1.52	1.52	170.0	90.4	90.4
7	13th	7	1.52	1.52	1.52	188.2	100.0	100.0

The percentage increase in dry weight of kernel on the basis of the total weight of mature kernel shows a somewhat regular pattern with two maxima. For the 7th, 8th, 9th, 10th, 11th and 12th months the percentage increase is 8.8, 24.3, 16.2, 15.5, 24.9 and 9.6 respectively (Table III). The percentage growth in the first and the last monthly periods are 8.8 and 9.6; similarly for the 2nd and last but one are 24.3 and 24.9 respectively and for the 3rd and last but two are 16.2 and 15.5 respectively. The rate of synthesis of kernel between the 7th and 13th month is thus symmetrically arranged with two maxima in the 8th and 12th months. Perhaps it may be a coincidence but it may also be noted that the rates of synthesis in the 7th, 8th and 9th months are very nearly in the ratio of 1 : 3 : 2 and similarly also the development in the 12th, 11th and 10th months.

TABLE II  
*Development of oil in growing coconut*

Serial No.	Period after flowering (beginning of month)	Growth stage	Per cent kernel Development	Oil content dry kernel per cent	Per cent oil development	Acid value	Iod. value of neutral oil	Sap. value of neutral oil	Per cent relative weight of oil per unit volume of fresh kernel on mature kernel
1	7th	1	0.7	31.0	0.3	..	27	..	2.5
2	8th	2	9.5	51.0	7.0	1.7	14.1	245	18.7
3	9th	3	33.8	68.6	33.5	1.6	8.9	246	50.0
4	10th	4	50.0	70.3	51.0	0.6	7.6	246	60.9
5	11th	5	65.5	69.5	66.0	1.1	7.5	244	71.0
6	12th	6	90.4	70.9	91.3	0.3	5.8	248	92.9
7	13th	7	100.0	69.0	100.0	0.3	6.6	248	100.0

*Development of fat during maturing of the coconut*

The data on the development of fat in the maturing coconut is given in Table II. The fat content of the kernels were determined by the following procedure: the kernels were sliced and dried first in the sun and then to constant weight in an oven at 60°C. About 3 gm. of dry kernel is weighed and mixed with 3 gm. of anhydrous sodium sulphate and 5 gm. pyrex glass powder and powdered finely in a mortar. The mixture is transferred quantitatively into a small glass percolator (diameter 2 cm., height 20 cm.) and packed over a bed of anhydrous sodium sulfate supported on a thin wad of cotton wool and percolated at room temperature with purified sulphuric ether freed from peroxides. The percolate is collected till 10 cc. contain less than 10 mg. of residue. The first 10-15cc. of percolate contain most of the fat and by the time 35-40 cc. is collected; the extraction is practically complete as shown by the next 10 cc. containing less than 6-7 mg. of residue.

The data in Table II show the following:

- that the oil content of dry kernels reaches a maximum value of 69.71 per cent and that this oil content is reached at the beginning of the 9th month after emergence of spadix, and within about 60 days of the starting of formation of kernels; the growth in the weight of the kernel continues for a further 120 days after this maximum oil content on dry weight of kernels is reached.
- kernel development and oil synthesis would have progressed only to about one third of the total by the beginning of the 9th month when maximum oil content of kernel is reached, and during the further period of maturing the same proportion of non-fatty material is laid down for unit weight of fat synthesised.

The percentage oil synthesised in the 7th, 8th, 9th, 10th, 11th and 12th months calculated on the basis of the amount of oil in mature kernel are 6.7, 26.5, 17.5, 15.0, 25.3 and 8.7 respectively (Table III). Here also there are two peak periods of oil synthesis, namely in the 8th and 11th months; two minimum periods of synthesis, namely 7th and 12th months and a middle period of about two months when the rate of synthesis is about 16 per cent of the total per month which is approximately double of that in the first and the last months.

TABLE III

*Monthly rate of synthesis of kernel and oil from 7th to 13th month in coconuts (on the basis of the mature nut)*

Serial No.	Period after flowering	Per cent kernel synthesised	Per cent oil synthesised
1	7th—8th	8.8	6.7
2	8th—9th	24.3	26.5
3	9th—10th	16.2	17.5
4	10th—11th	15.5	15.0
5	11th—12th	24.9	25.3
6	12th—13th	9.6	8.7

*Variation of iodine value of oil during the maturing of the coconut*

It has been pointed out earlier that in the case of all dicotyledonous plants reported so far, the iodine value of the fat either remains constant throughout the ripening of the seed or, as is more frequently the case, increases progressively as the seed matures, the highest value (these are the normal values for the fat) being reached only when ripening is practically complete. In the case of coconut oil the figures in Table II show a small decrease in the iodine value as ripening proceeds and this may at first sight be taken for a decrease in iodine value of fat as ripening progresses.

It appears more probable, however, that this decrease in iodine value during maturing is not due to any decrease in iodine value of the kernel fat but due to an entirely different reason. There is a thin brown testa immediately beneath the shell and the endosperm is attached to this testa. It is difficult to remove this testa



from the adjoining kernel, particularly in the earlier stages of growth when the kernel is not very firm. This testa contains oil of a type different from that in the kernel or meat [Armstrong and Allan, 1924]. For the present studies the testa was removed as carefully as possible from one mature nut by means of a sharp knife after cutting the kernel into thin slices and was dried to constant weight in an oven at 60°C. which amounted to 8 gm.; the total kernel, i.e. meat and testa weighing about 190 gm. The testa thus obtained was not completely free from all traces of meat but this is not likely to have been above about 5 per cent or so of the total. The oil content of this as well as the similarly dried white meat from the same nut were determined by the method already described which came to 41 and 69 per cent respectively. The oil from the testa had iodine value 49 and saponification value of 220 after removing acidic matter by treatment with alkali in ether solution; the oil from the white meat, after similar treatment gave iodine value 8.5 and saponification value 250. In the mature nut the testa comes to 4 per cent of the total kernel, and would contribute 2.2 per cent of the total oil in the kernel or slightly less; this is too small an amount to produce any noticeable difference in the constants of the coconut oil.

This testa is, however, laid down first and the development of meat follows the laying down of the testa. A period of maturing may be necessary for the testa, but nevertheless, throughout the initial stages of growth the testa is likely to be in a more advanced stage of maturing than the meat, particularly in the very early stages where the proportion of total kernel is less than about 10-15 per cent of the mature kernel. Hence in the initial stages of growth when the total kernel is extracted, the oil is likely to contain proportionately larger amount of oil derived from the testa and this will come down steadily as ripening proceeds. This is exactly what appears to take place. In the first stage of growth examined (6 months after emergence of spadix) only about 0.3 per cent of total oil had been synthesised and the oil showed iodine value of 27; in the second stage (7 months) when the per cent oil synthesised was about 7 per cent, the iodine value fell to 14 and by the time the 3rd stage (8 months) reached (33.5 per cent oil synthesis) the iodine value reached the virtually normal figure of 8.5 and showed only very slight variations further.

It appears reasonable hence to conclude that the oil found in the ripening coconut at all stages of growth shows practically the same chemical characteristics as that in the mature nut, i.e. iodine and saponification values. Coconut oil contains a large number of fatty acids of widely differing molecular weights and the constancy of the mean molecular weight of the total fatty acids in all stages of growth indicates that the fatty acid synthesising enzyme system in the nut has got the characteristic ability to build a specific mixture of acids having the same mean molecular weight throughout the period of synthesis and this confirms the suggestion made by Kartha [1953] that enzyme systems in specific fat depots may possibly be specific to specific mixtures of saturated fatty acids having same mean molecular weight.

## SUMMARY

The weight of kernel, and yield, saponification value, acid value and iodine value of oil in maturing coconut at 7 different stages (monthly intervals) have been studied. The oil from the white kernel differs somewhat from the oil from the brown testa. The kernel appears to synthesise oil with the same characteristics as ordinary coconut oil from the beginning to the end of ripening. The oil content on dry weight of kernel reaches a maximum value of about 68-70 per cent by the beginning of the 9th month after flowering and thereafter remains constant; at this time the kernel and oil development comes to about 33 per cent of that produced in the mature nut.

This appears to be the first reported study of the development of oil in a palm, or in a monocot.

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# UTILIZATION OF MANGO IN THE PREPARATION OF FRUIT CEREAL PRODUCTS

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(With one Text-figure)

FROM the point of view of average production, the mango is easily the most outstanding of all Indian fruits [Naik, 1947]. It occupies about 70 per cent of the total area under fruits [Katyal, 1952] and is the most important commercial fruit crop of the country. But unfortunately, the storage life and season of availability of this fruit, are rather short. Further, lack of suitable marketing facilities aggravates the problem of economic disposal of large quantities of the fruit. A considerable proportion of the total produce, therefore, goes waste. In the canning of this fruit large quantity of pulp is obtained as a by-product. A substantial quantity of this pulp also does not find any economic use.

The existing methods of preservation and processing of the fruit are regarded as inadequate to cope with the problem of waste. Investigations were, therefore, undertaken to develop some new ways for the utilization of mango pulp. The practice of consuming mangoes along with *chappatis* and the use of mango pulp in a number of home preparations in many parts of the country suggested the processing of pulp and cereals together into some suitable products. Cruess [1940 ; 1945] has used dried fruits, chiefly prunes, in the preparation of breakfast cereals and has indicated good commercial possibilities for these products. Preliminary work done by the present authors [Lal *et al.*, 1955] has shown that fresh fruit pulps from mango, papaya, etc. can be incorporated into cereal products like flakes, vermicelli and flour. This deals with further studies in the preparation of these products from mango pulp and the determination of their nutritive values.

## EXPERIMENTAL

Fully ripe *Rasputri* mangoes were chiefly used for these experiments. The pulp, prepared by means of a pulping machine, was passed through a stainless steel sieve of 80 mesh. The pH of the pulp was adjusted at different levels by adding  $\text{NaHCO}_3$ , in order to determine the proper pH at which the product will not curdle hot milk. Uncooked, cooked and semi-cooked whole wheat flour sieved through 80 mesh sieve ; *maida*, i.e. fine wheat flour completely free from the bran layer, and some commercial starches were used in various proportions for mixing with the fruit pulp in order to prepare the flakes, vermicelli and flour. Drying was done in the sun as well as by artificial heat in a natural draft cabinet drier, air blast cabinet drier,

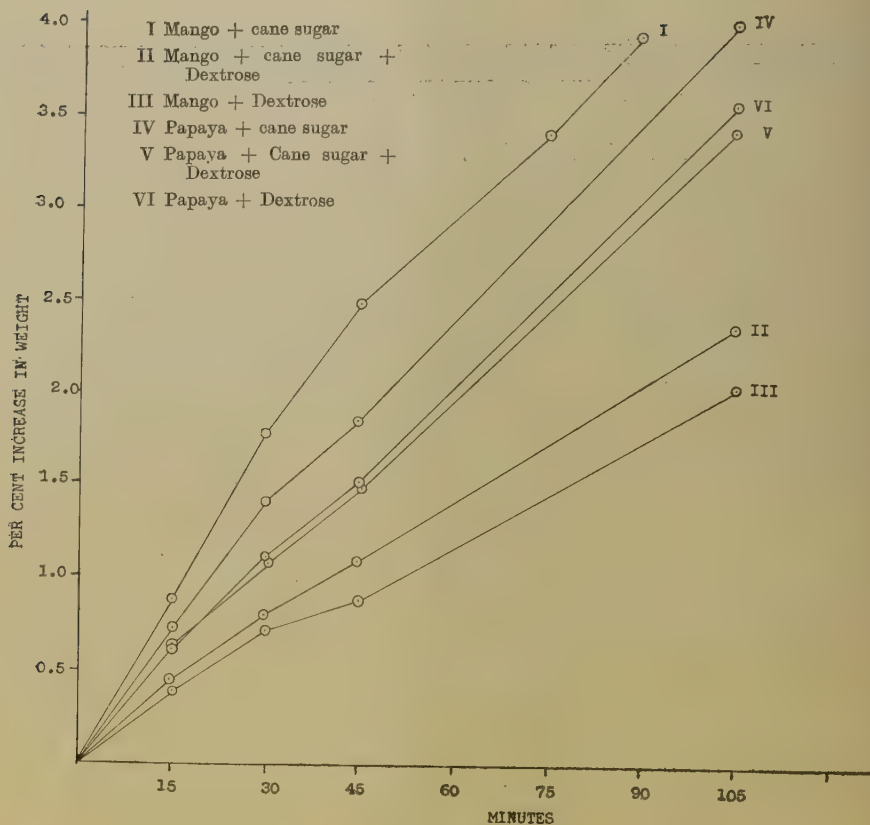


FIG. 1. Moisture-uptake by fruited flakes on exposure to atmospheric humidity



vacuum shelf drier, or vacuum drum drier. Different drying temperatures were applied in the case of drying by artificial heat, to determine the best conditions for drying each of the three types of products.

Preliminary experiments [Lal, *et al.*, 1955] had shown that the addition of sugar in the preparation of mango cereal flakes was necessary from flavour point of view. The flakes prepared with the addition of cane sugar (sucrose) were, however, found to be very hygroscopic in nature. In the present experiments, sucrose was replaced fully or partly (50 per cent) by dextrose and the samples obtained were tested for their water uptake affinity by exposing 20 gm. samples in flat dishes to atmospheric temperature and humidity. For this test, flakes were prepared both from mango and papaya pulps.

In all these cases, the general quality of a product was determined by panel of tasters on the basis of texture, appearance, taste and odour of the cooked or otherwise prepared products. Based on these findings, the recipes and the methods of preparation of the products were standardised.

The loss of ascorbic acid and carotene during the preparation of the products from mango pulp were also determined. Ascorbic acid was estimated by the method of Robinson and Stotz [1945] and carotene by the official method of the Association of Vitamin Chemists [1947] using  $K_2Cr_2O_7$  standards.

## RESULTS AND DISCUSSION

The moisture-uptake by the different lots of flakes is shown graphically in Fig. 1. It will be seen that by replacing 50 per cent of the added sugar in the formula by dextrose, the moisture-uptake was reduced by more than 50 per cent in the case of mango flakes. Papaya flakes were less hygroscopic than mango flakes but the same effect of dextrose was noticeable in this case also, though to a lesser degree. It will also be noted that there was no marked difference in the results obtained by complete and 50 per cent replacement of the sugar by dextrose.

Based on the results of experiments conducted, the following methods of preparation have been standardized.

**Flakes.** Whole white wheat is cooked in an equal quantity of water for 30 minutes at 10 lb. steam pressure in a pressure cooker. The cooked grains are dried in an air-blast drier at 80°-90°C to their original weight, milled and finally sieved through 80 mesh sieve.

The fruit pulp, as prepared by means of a pulping machine, is screened through a stainless steel sieve of 80 mesh and its pH adjusted at about 5. This is done by partial neutralization of the acidity with  $NaHCO_3$  added to the pulp in the form of an aqueous solution.

For every 15 lb. of this pulp, 1 lb. of the cooked wheat flour and 8 oz. each of cane sugar and dextrose are added. These are mixed thoroughly, passed through a homogeniser and put through a vacuum drum drier operating at 25 in. vacuum in the drying chamber and 35 to 40 lb. steam pressure in the drums. The drum clearance is adjusted at 0.006 inch, and the speed of drum rotation at 7 R.P.M.; the length and the diameter of the drums being 7.5 and 6.0 inches respectively. The dried product is broken into flakes and immediately packed in friction-top tins or other moisture-proof containers. One hundred pounds of mangoes yield about 15 lb. of flakes.

The flakes are crisp, attractive brownish yellow in appearance and have a distinct but mild flavour of mango. Organoleptic tests indicated a high consumer appeal for this product when used as a breakfast cereal like corn flakes. The product packed in friction top tins and sealed glass jars, has been found to keep well with regard to appearance, texture and organoleptic qualities, during storage for nine months.

*Vermicelli.* The fruit pulp is prepared and its acidity neutralised in the preparation of flakes. This is then concentrated, avoiding scorching, in a steam jacketted stainless steel kettle or over open fire in a stainless steel vessel, to reduce it to about half its weight. White wheat flour (80 mesh fine) equal to the quantity of original fresh pulp is then added to the hot concentrated pulp. The fruit-cereal mix is made into a stiff dough by thorough kneading and extruded through a vermicelli press to get slender strands of vermicelli which are then dried by artificial heat in a natural or forced draft cabinet drier, at 60°C. The dried product is broken into smaller strands of convenient length and packed in friction-top tins or similar suitable containers. One hundred pounds of mangoes yield about 30 lb. of vermicelli.

The vermicelli, prepared as above, is smooth and hard in texture and attractive light yellow in appearance. When cooked in milk in the same way as the common cereal vermicelli, it is highly palatable and has a fruity flavour. The product, packed in the same way as flakes showed satisfactory keeping qualities during storage for 10 months.

*Flour.* The fruit pulp is made free from skin particles, fibre and hard bits by passing it through a sieve of 40-50 mesh. The acidity in excess of 0.5 per cent (as citric acid) is neutralized as above with  $\text{NaHCO}_3$ . It is then mixed well with one-fifth of its weight of wheat flour and spread in layers of about 1 cm. thickness over aluminium trays. Drying is done in an air-blast drier at 70°-80°C for the first two hours and subsequently at 55°-60°C. After drying to a semi-solid state, the product is scraped in order to loosen it from the tray surface for efficient drying. Drying is continued further to a bone-dry stage followed by milling to get the flour. The flour is again put in the drier in thin layers over trays for a further period of

about one hour in order to remove the moisture absorbed during milling. The flour should be packed in moisture-proof containers to prevent caking during storage. One hundred pounds of mangoes yield about 18 lb. of flour.

The flour thus prepared is brownish-yellow in colour. It has been used successfully for the preparation of *parotha*, *chappatis*, *halwa* and other preparations where cereal flour is normally used. Mango *parotha*, in particular, is very attractive and appetising. Preliminary trials have revealed that good quality cakes can also be made from this flour. Packed in sealed friction-top tins and glass jars, the flour has been found during storage for 10 months to keep well in all respects.

The composition of the mango-cereal products mentioned above, with respect to their fruit-cereal-sugar makeup, and also their ascorbic acid and carotene contents are presented in Table I. The loss of the latter two constituents during the preparation of the products are shown in Table II.

TABLE I

*Proximate fruit-cereal-sugar makeup of mango-cereal products and their ascorbic acid and carotene contents (values expressed on dry weight basis)*

Product	Moisture (per cent)	Fruit (per cent)	Cereal (per cent)	Added sugar (per cent)	Ascorbic acid (mg./100 gm.)	Carotene (mg./100 gm.)
Flakes	1.0-2.5	60	20	20	3.0	8.8
Vermicelli	5.0-6.0	30	70	..	Trace	4.1
Flour	2.0-3.0	50	50	..	Trace	7.6

TABLE II

*Losses of ascorbic acid and carotene during the preparation of mango cereal products*

Product	Moisture (per cent)	Fruit solids calculated (per cent)	Ascorbic acid (dry weight basis)			Carotene (dry weight basis)		
			Calcu- lated (mg./ 100 gm.)	Actually present (mg./ 100 gm.)	Loss (per cent)	Calculated (mg./ 100 gm.)	Actually present (mg./ 100 gm.)	Loss (per cent)
Mango pulp	82.20	17.80	..	16.14	..	..	22.07	..
Flakes	1.47	58.00	9.20	3.00	67.4	12.79	8.80	31.2
Vermicelli	5.20	30.86	4.98	Trace	Complete	6.81	4.12	39.5
Flour	3.01	48.50	7.72	Trace	do.	10.70	7.60	29.0

It will be seen from Tables I and II that the mango-cereal products are good sources of carotene but are deficient in ascorbic acid. Further experiments on fortification of the products with added ascorbic acid are in progress.

## SUMMARY

The methods of preparation and the recipes of three mango-cereal products, viz. flakes, vermicelli and flour, have been worked out. As judged from organoleptic tests, the products are highly palatable. They have also been found to be good sources of carotene. Under proper packing and storage conditions all the three products were found to possess good keeping qualities.

## ACKNOWLEDGMENT

The authors are thankful to Dr V. Subrahmanyan for his keen interest in this investigation.

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## REVIEW

### SMALL FRUIT CULTURE

BY J. S. SHOEMAKER

*(Published by McGraw-Hill & Co. Inc. New York Toronto London, 3rd Edition, 1955, pp. 447. Price \$ 6.50)*

THE book on small fruit culture by Prof. J. S. Shoemaker contains six chapters. Each chapter gives detailed account of grape culture, strawberry culture, bramble culture, currant and gooseberry culture, blue berry culture and cranberry culture. The information covers all aspects starting from a brief history and followed by a list and description of varieties, propagation methods, cultural practices, harvesting and marketing, and insect pests and diseases and their control. The material has been collected from a vast but scattered literature on small fruits. In addition to this, the growers' experience, the suggestions from specialists and the valuable experience of the author are also included.

More than 200 new references have been added to this new edition bringing the total number to 621. This shows the great progress that has been made during recent years in the culture of small fruits. The number of illustrations has also been increased from 52 to 75 in this edition.

Newer varieties of different fruits, important cultural and irrigation methods, and up-to-date information on training methods are some of the new features of this edition.

The fact that the author of this valuable book had to revise it for the third time and reprint the first two editions four times since it was first published in 1934 speaks of the great popularity that this book enjoys. Although the general set up of the text remains much the same as in earlier editions, the present one is a definite improvement inasmuch as many new and important developments that had taken place during the last decade have been incorporated.

The general setup of the book is indeed excellent in the present edition. Although the price of this edition has almost been doubled, it is more than justified by the art paper used, the photographs, the illustrations, the new headings and sub-headings used and the beautiful printing that have given a new shape to this book.

The author, Dr. Shoemaker is an experienced professor of Horticulture at the Ontario Agriculture College, Guelph, Ontario (Canada) and a horticulturist of great eminence. He has presented the research work so far carried out on small fruits in a simple and lucid style. The book is considered to be of great utility not only in institutions, research stations and Universities, but also for growers interested in the cultivation of small fruits. (S. S.)





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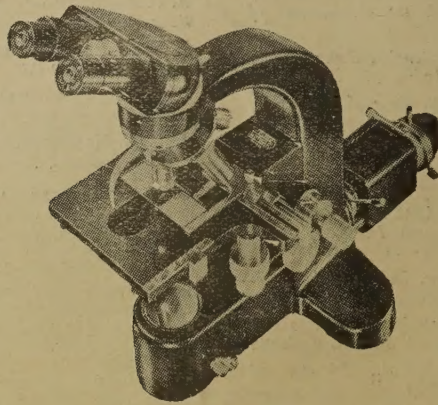
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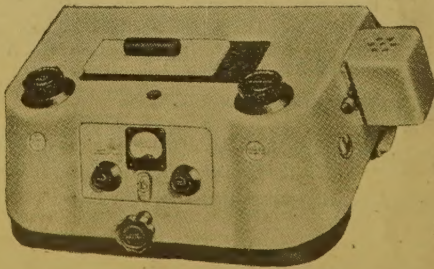




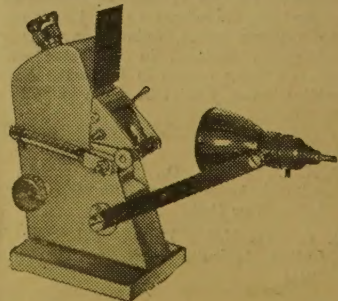
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